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PENDULUM CHRONOSCOPES AND ACCESSORIES FOR PSYCHOLOGICAL EXPERIMENTATION.

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In connection with his work as director of the psychological laboratory of Indiana University, which position was held till August 1, 1908, the writer had occasion to attempt to develop chronometric apparatus both for research and for the student practice course. Partial notices of these attempts have occasionally appeared, but no complete account such as is here given. In the PSYCHOLOGICAL REVIEW, Vol. 7, No. 5, 1900, the writer described 'A Type of Pendulum Chronoscope and Attention Apparatus,' the construction of which was suggested particularly by accounts of the Fitz pendulum chronoscope. The chief difference between this and the model constructed by the writer lay in the mode of carrying and clamping the index. In this first model, the axis of the pendulum was so cut that its knife edges were exactly in line and in the middle of the axis so that a further extension of the axis, which carried the index, rotated as if the axis were in circular bearings when the pendulum moved. The index was attached to a soft iron disc, which could rotate on the extension of the axis and was pushed by a spring against a friction disc attached to the end of this extension. A magnet fixed to the bracket, on which the axis of the pendulum rotated, could be made to attract the soft iron disc carrying the index, and fix it in position. When the disc of the index rested against the friction disc of the axis, it was held in place sufficiently firmly to follow the movements of the pendulum accurately. On the attraction of the index disc from the fric-

tion disc to the magnet, the friction keeping the index moving with the pendulum was greatly reduced and the index disc was held firmly in position against the magnet, with its point against the scale. The pendulum could swing on fairly freely and was caught at the end of the return swing by teeth on the escapement armature. The interval measured was the interval between the release of the pendulum by the escapement and the arresting of the index. The first chronoscope had mercury cup arrangements for intervals and a movable bob for securing different rates. In the later models these have been replaced by devices both more nearly accurate and more convenient. In the first model the release of the pendulum was not noiseless and was therefore defective. However, from the point of view of accuracy, aside from the work of the two devices just mentioned, the work of the first pendulum chronoscope seems to have been as good as that of later models.

To remedy the defects of the first model and to produce a more finished piece of apparatus, a second model was designed. This is the most complete form yet constructed, as the third is only a simplification of the second. Of this second model no detailed description has been published till this present article. It was constructed from the writer's designs by Stoelting and Co. of Chicago and formed a part of this firm's exhibit at the St. Louis Fair in 1904. A cut of model No. 2 appeared in the Indiana University book, published for the same fair.

In model No. 2, the release and catch of the pendulum is of the same sort as in model No. 1 except that it has been made silent by preventing the armature from touching the magnet of the escapement. As in the first model, the release and catch has several notches so that the pendulum may be caught on the return swing by some one of them, according to its retardation. In some, perhaps all other, pendulum chronoscopes, the holding and release of the pendulum for a record is secured by having a magnet hold the pendulum directly at the beginning of its swing, the pendulum beginning its swing when the current is broken. That this last form of release is also good seems evident, and which of the two types of release will be adopted in the construction of pendulum chronoscopes cannot be pre-

dicted with certainty. Both are silent, which is essential, if the experimenter would avoid unnecessary trouble and inaccuracy. However, in case the pendulum is held directly by a magnet some variation may be expected from differences in its retardation, due to differences in the duration of the current and differences in the weight of the pendulum for fast and slow rates, as well as differences in annealing. These effects are largely avoided in the escapement used. The pendulum is released by the making of the circuit of the escapement magnet which may therefore be supposed to be in the same condition for every record, and a current is used which is twice as great as is necessary to release the pendulum for the fastest rate, when it bears most heavily on the tooth of the escapement. Only the form of escapement peculiar to this instrument has been used with these chronoscopes so the writer has made no experimental comparison of the two types. However, in testing chronoscopes 1, 2 and 3 with the simple falling ball apparatus, in which the falling of the ball is comparable with the falling of the pendulum with the simple magnet escape, the chronoscopes seemed to be more accurate than the testing device, because of variations in the hysteresis of the ball and the magnet holding it. Systematic rotation of the ball, which was probably not so well annealed as it should have been, and the use of a current barely sufficient to hold the ball gave the best results.

For rapid action of the magnets, the cores must be comparatively large with few windings of wire. A convenient size of the magnets both of the escape and the index is one that will require the use of the same or of equal currents to make the chronoscope give the correct time. In the first models of chronoscope No. 2 an error was made with regard to this matter so that a stronger current was required for the escapement than for the index.

The different rates of swing of the pendulum are secured by screwing on the necessary counterpoises. In model No. 1 these rates were secured by raising and lowering an eccentric bob, which also permitted the experimenter to adjust the pendulum so that it would hang vertically. The plan of detachable counterpoises, which has usually been employed in pendulum chronoscopes, seems to be the more convenient.

Instead of the semicircular mercury cups for securing intervals, as in No. 1, a system of one fixed and two movable keys on a curved slide is employed. These are both more accurate and more convenient than the mercury cups. They can be used for definite intervals for any purpose. In the laboratory of Indiana University they have been used especially for giving the time of

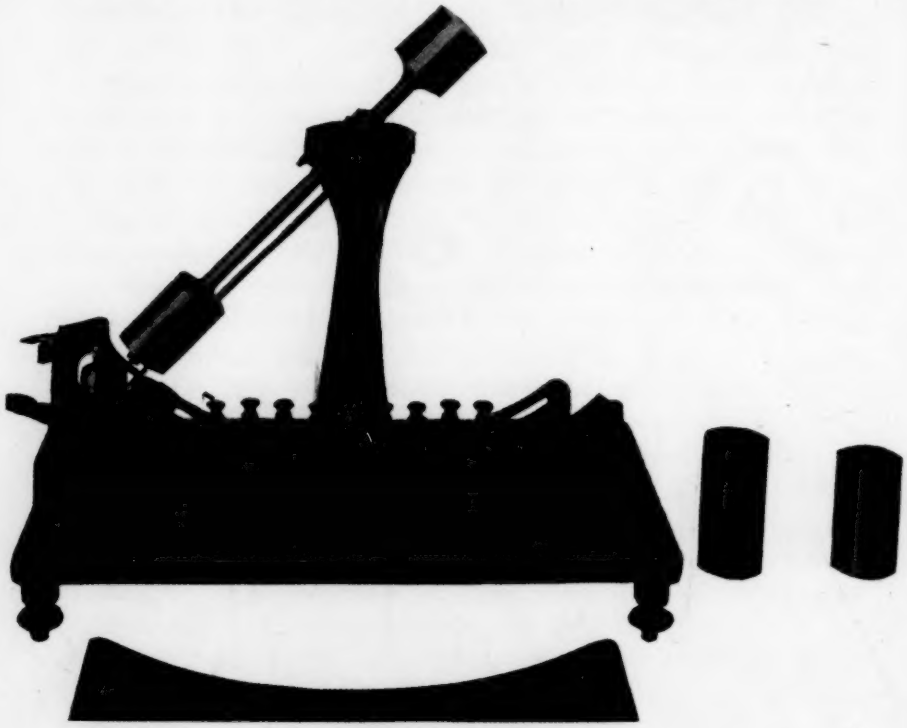

FIG. 1. Model No. 2.

exposure in tachistoscopic experiments, and in standardizing the smaller pendulum chronoscopes of model 3. A laboratory equipment consisting of one chronoscope of the type of model 2 and several of the type of model 3, especially for student use, seems to meet most actual needs.

The contacts in the small movable keys are kept together by having a pointed projection of the lever making the contact just slip over a triangular tooth on a short spring. When the lever

is struck by the pendulum and is moved a short distance, perhaps less than half a millimeter, the projection slips over the tooth,

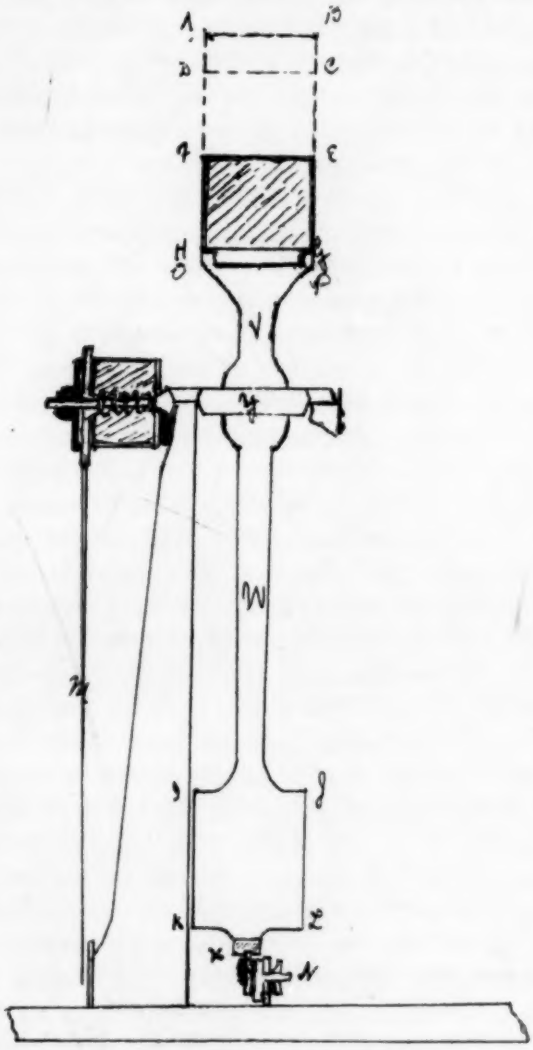

FIG. 2. Pendulum of Model No. 2.

which then throws it out of the way. By this means sufficient pressure at the contacts is secured and the resistance to the pendulum is made small.

The pendulum is so constructed that with its three counterpoises it will swing at three different rates, namely, at one half, one and two seconds for the half swing. Fig. 2 gives the proportions of the different parts of the pendulum graphically. The distance *X–Y* is 20 cm.; *Y–OP* is 5 cm.; *OH* is 6 mm.; the thickness of *V* is 1 cm.; of *W* 1 cm. at the top and 0.8 cm. near *I. J*; *IJ* is 4 cm., *JL* 5 cm.; and *HG* is 4 cm.; *HF* is 3.4 cm.; *HD* is 6.5 cm.; and *HA* is 8 cm.; *HFEG* is hollow with a .75 mm. wall, except at *HG* where the thickness on each side of the screw is 1 mm., though when it is fully screwed on, *HGPO* is to be practically solid. Parts *HFEG*, *HDCG* and *HABG* may be changed to give respectively half swings of .5, 1 and 2 seconds. *M* represents the index and *N* a cross-section of one of the movable keys.

The length of the scale arc is about 29 cm.

To secure correct proportions in the construction of this pendulum requires considerable time and skill; and in the simplified form, No. 3, only an approximation is attempted. The calibration of the scale is done in essentially the same way in all cases, except that the procedure was somewhat simplified in connection with the construction of model 3. The calibration is both easy and accurate and consists essentially of letting the sparks from an induction coil actuated by an electric tuning fork of 100 vibrations a second run over the piece from which the scale is to be made, after it has been smoked. Not all tuning forks even by the best makers give the correct number of vibrations; different conditions must also be taken into account. Some correction of the tuning fork may therefore be necessary. The method of securing the spark records for the scale has been the same throughout, though a couple of minor improvements have been introduced. A very fine wire is run down the index and the end turned toward the scale. The upper end has a hook at the level of the axis and rests in a mercury cup. The formation of the spark circuit can easily be imagined. To make the pendulum start at a certain point between the sparks, a rather complicated system of wiring and balancing of currents was at first arranged, so that when the escape was gently shaken by the primary giving rise to a spark another current

would be switched in to pull the escape down. This plan gives good results and the spark can be run over the same record several times with coincidence. The pendulum will by this plan also start at corresponding points for different rates. However, the method is complicated and a very simple device has been introduced which serves fully as well.

With both methods the escapement is so placed as barely to hold the pendulum. With the new plan, a good-sized permanent magnet is placed over the back projection of the escapement lever so that this will fly up to the magnet when the escapement is given a very slight shake. This shake is given to it by the interrupted current of the primary and usually in the same way on the closing of the primary circuit, at least so that several coincident spark records may be obtained. The second change in the making of the spark records was that of omitting smoked paper and smoking directly the piece intended for the scale, which seems to give better results.

Two points should be noted in levelling the chronoscope. Each instrument has a universal level attached. By the aid of this it can be approximately levelled, but this procedure should be supplemented by seeing that the index runs the full length of the scale. With the combination of these two ways errors from levelling should be very small.

Nearly all the different time measurements fall conveniently within the limits of the forward swing one scale or the other. Occasionally a record is longer, in which case the time is ascertained by noting the point at which the index stops on the return or subsequent swings.

The three scales are not equally valuable, the half second and two second scale being more serviceable. In model No. 3 only these two are used and the one second scale could be omitted in model No. 2, but it seems sufficiently useful to be retained in the complete instrument.

Fig. 3 represents model No. 3 with all the accessories, that is, with a complete outfit for the usual chronometric experiments of the laboratory. Model No. 3 was designed not so much for research as for the student practice course, though it can serve for either as far as accuracy is concerned. It differs from No. 2

chiefly in being smaller, much simplified, and in having the especially expensive features eliminated so as to make it possible for a laboratory to have a considerable number of duplicates for general student practice. The base is 25 by 15 cm., while the base of no. 2 is 38 by 21 cm. Other parts are proportionally reduced. The base is made of cast iron, left without planing. The pendulum bracket, which is 15 cm. high, is cast solid and the rests for the knife edges of the pendulum, which in model 2 are separate pieces of hardened steel, are planed out with a properly shaped tool and left without hardening. The pendulum instead of being made from a solid piece, as in model 2, is a composite. A half inch brass rod is selected and a screw thread cut at one end. Pieces of the proper shape for the lower bob and the expansion to hold the axis are soldered on. The upper bob with its detachable part, to be used to secure the slow swing, is screwed on, the fixed part being soldered. The pendulum is then adjusted so as to give a half swing in from 450 to 500 σ and a slow swing of about 2000 σ or more. The scales for the two swings are made on opposite sides of the same piece of brass; and either side can, of course, be presented by lifting the brass piece out of its guides and putting it in the required way. As these scales are then made from a spark record in the way indicated, theoretically no part needs to be constructed with special accuracy, unless it should develop some irregularity of motion. Among the things needing most care in construction are the axis with its knife edges, the knife edge rests, the hole in the pendulum for the axis, the index armature, the armature of the escapement, and the scales; but for this ordinary good workmanship will probably do.

To make it possible to use the return swing accurately, it is necessary to make the measurement of some known interval longer than the first half swing so that the index will be stopped on the return. With this as a point of reference, the return swing can be read with sufficient accuracy and the proper values can better be assigned to the more thickly crowded divisions at the end.

The difference in the usefulness of models 2 and 3 is represented chiefly by the omission in model 3 of the sliding keys and

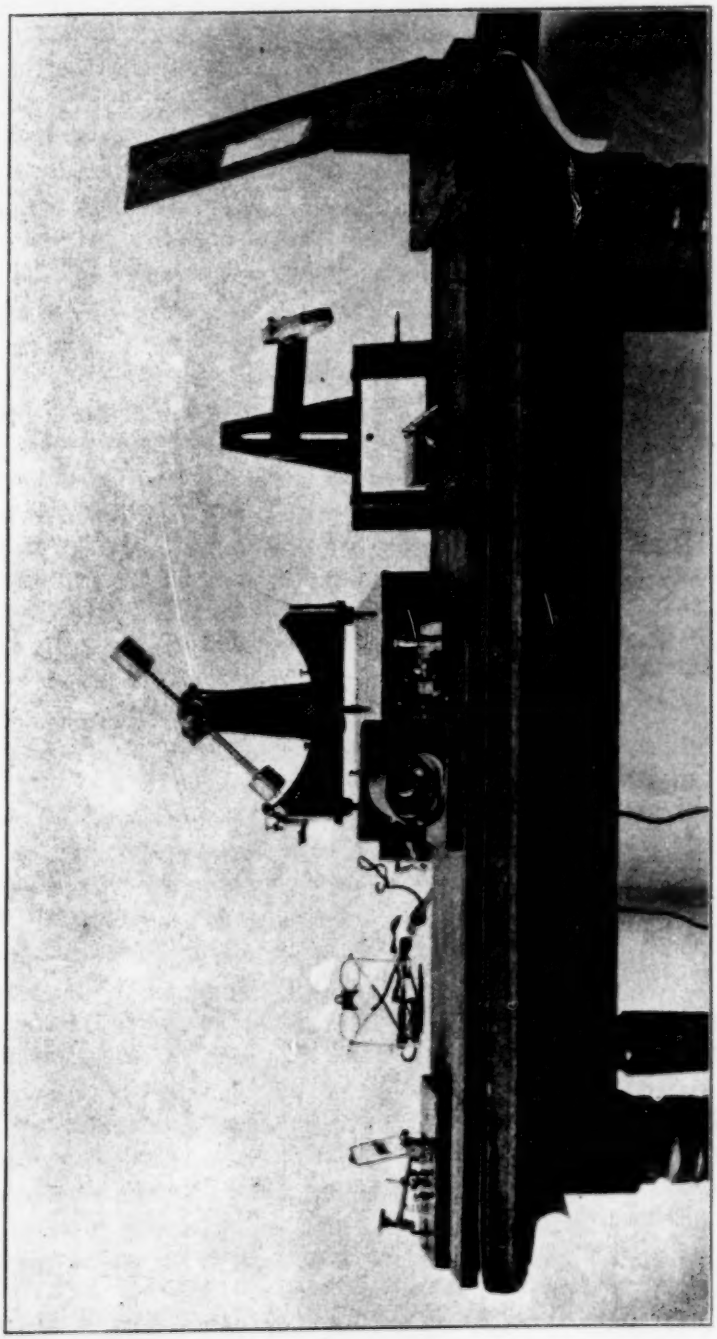

FIG. 3. Model 3 with Accessories.

so of the possibility of using it for securing intervals for tachistoscopic exposure, standardizing other instruments, giving the second signal in complication attention experiments, and for other purposes requiring intervals.

It is, of course, possible to conceive of other types of pendulum chronoscopes, which yet retain the essential features of those here described, especially a fourth, that would have the features of model 3 for reducing cost of construction and at the same time the sliding keys of model 2 for intervals. With such an instrument almost everything could be done that can be done with this line of chronoscopes, and the cost should be much less than for model 2. In size this instrument might be the same as model 2 or between model 2 and model 3, which would perhaps be preferable. The pendulum would need to be somewhat heavier than that in model 3, for the operation of the keys. With one instrument like model 2 and several like model 3, there is, of course, no special occasion for the construction of an instrument of this type and none has been made. But if there were to be but one instrument and model 2 would appear to be too expensive, then the proposed model 4 would seem to meet the requirements.

The accessory apparatus for signals and reactions has been devised to secure accuracy of experimental conditions and at the same time simplicity and convenience. Figure 3 shows the entire outfit. It consists of a board about four feet long, with the various pieces of the accessory apparatus attached. As has been stated, chronoscopes of types 2 and 3 start silently and operate silently till the index is clamped in the reaction. Apparatus for touch and visual stimulation must also operate silently, while the specific function of apparatus for auditory stimulation is to give a regulable noise at the instant of the closure of the circuit for starting the chronoscope. As is well known, reactions for auditory stimulations are shorter than for visual stimulation and for touch stimulation in certain localities, and all reactions are likely to be reduced to auditory reactions, if there is any sound in connection with the different stimulations. It is not safe to trust the reactor's statement as to which stimulation is being followed. He may not be aware that he

is reacting to certain clicks of the chronoscope when he should be reacting to visual stimulation. If the reactor is near the Hipp chronoscope, for example, visual reactions are quite likely to be in reality auditory, due to the sound connected with the beginning of recording by the chronoscope, even though this is so muffled as to be only slightly audible and the reactor himself is not aware that it plays any part in his work.

In the first place, an effort has been made to avoid most of the trouble connected with the setting up of the chronometric apparatus, and especially the trouble connected with changing from one form of reaction to another. The labor of changing is likely to fall on the assistant in the laboratory or on the instructor, rather than on the student; and with a large number of students this introduces a very considerable and unnecessary burden. There is usually not sufficient time for the extended study of the physics of the problem and learning merely to imitate the manipulation of the wiring has probably not sufficient educational value for the time expended. Apparatus for the different forms of stimulation can be ready for use, and in circuit with the chronoscope at the same time, requiring only that a card be slipped in to separate the contacts of the apparatus for touch stimulation in case it is of the break circuit form and is not in use, and for visual exposures of words or figures, that the mirror key be moved from one end of the four foot board to the other and a card holder be substituted for the lens. A card would also need to be slipped between the contacts of the face key, if the break circuit form were used. These changes are slight, however, compared with the labor of setting up separate forms of apparatus for these purposes, especially if correct experimental conditions are to be observed.

While practically all the accessory apparatus is somewhat different from that in use with other instruments, only the device for light stimulation and the exposure of letters, words, figures, colors, etc., is so different that it could not easily be replaced by apparatus of the usual type. For mere light or color stimulation, the mirror key, large lens, and shield with circular opening are required. The circular opening is covered with one or more thicknesses of tissue paper. When the mirror key is

pressed down, at a certain point in its movement, an image of the light will be thrown on the circular opening and the chronoscope will be started at the same instant. This coincidence of the image and the starting of the chronoscope is secured by adjustment. The mirror keys actually in use have an arc at the end of the lever against which a contact spring rests. It is partly insulated so that for a certain distance it can bear against it without starting the pendulum, while this is started when it reaches a certain point in the arc. It is at this point that the image of the light is to be thrown on the circular opening, which occurs without its appearing to come in from below. The purpose of the arrangement, aside from securing contact at a certain point of the movement, is to reduce the sound of the contact so that it will be inaudible to the reactor. If the

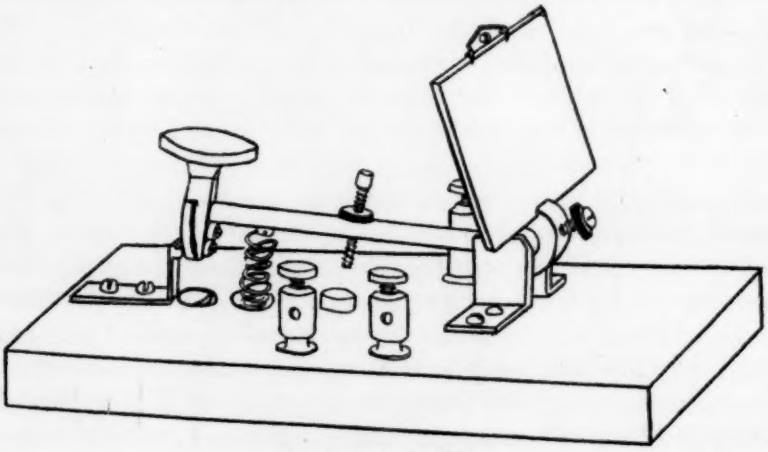

FIG. 4. Mirror Key.

key is well made this is the case, but might not be so after it has become worn. On the whole it seems more convenient than a silent key of the mercury type, as it has to be moved about, even though it will require occasional care. However, the latter might be preferred by others and one could be more certain that it would be sufficiently silent. The source of light for the mirror key shown in Fig. 3 is an electric light placed a little to the left of the middle of the board. This position is not a necessary one and for some reasons a position above the

board would be preferable. Stimulation by different colored light is secured by putting different colored glasses before the source of light. In doing this care must be taken that the illumination of the surroundings be not sufficient to betray the color.

To arrange for the exposure apparatus, the mirror key is transferred to the other end of the board directly under the shield. Two metal posts at either end of the board make this change of position easy and at the same time secure the necessary connection with the chronoscope. The exposure apparatus is shown in Fig. 5. It will be seen that a mirror is placed a

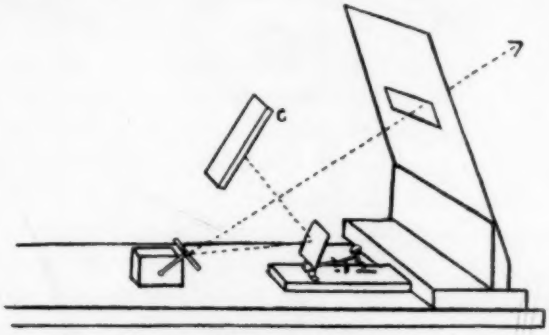

FIG. 5. Exposure Apparatus.

little to the left of the key and that a card holder is substituted for the lens. The subject sees the words or figures in the fixed mirror. When the mirror key is pressed down so as to bring the words or figures into position, it is impossible to tell what they are during the movement, but it becomes possible as soon as the mirror key is arrested, as it is by striking a fixed contact, which has been substituted for the arc contact. The conditions for visual accommodation and fixation seem satisfactory. The words or figures disappear when the mirror key is allowed to move away from contact. If the mirror key were moved by an electric magnet and the current regulated by an interval apparatus, such as that of model 2, this exposure apparatus could be used accurately as a tachistoscope. By some practice, it is possible to press the key down so as to make contact to from one tenth to one twentieth of a second and most of the im-

portant facts of tachistoscopic work can thus be demonstrated, without the attachment of the electro magnet, though, of course, not with satisfactory precision. The position of the card holder is such as to require care in securing its proper illumination. What is seen is seen after double reflection. On the whole good

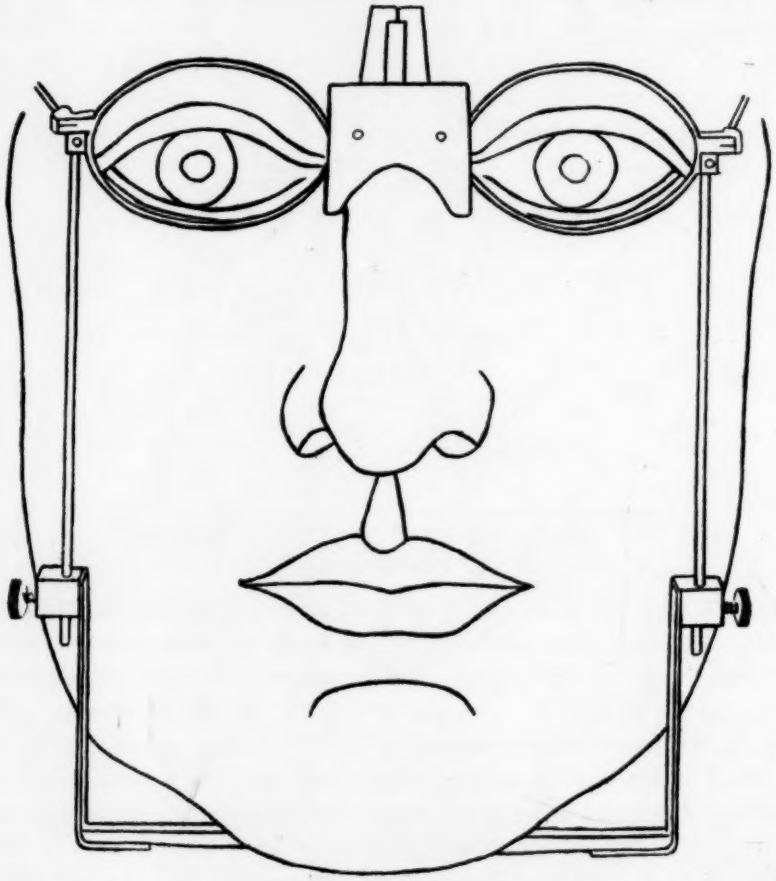

FIG. 6. Face Key.

mirrors of the usual sort, with the silvering on the back will probably in the long run be more convenient, but much better results for a time are obtained by silvering the front surfaces both of the fixed mirror and the mirror of the key, for which glass with an even surface should have been secured. How-

ever, front silvering tarnishes and would have to be repeated every few months to keep the mirrors ready for constant use, but the results are so much better that the trouble is at least worth while for the enthusiast.

The face key, Fig. 6, for showing that there has been the beginning of a movement of the lower jaw, as in beginning to speak a word, is probably next in the degree of difference from apparatus ordinarily in use. The recording of this reaction accurately is difficult and a little practice is necessary to secure good results. As has been stated, the key records merely the time of opening the mouth. Some subjects will open the mouth before they are ready to react. If this occurs, they must be trained to wait until they begin to express a word by this movement. The key has been made only in the break circuit form, but can, of course, also be made in the make circuit form. In the pendulum chronoscopes here described, all the circuits are make circuits, which in case break circuit keys are used, requires that they be used as short circuits. In the case of the break circuit keys of the interval apparatus, they must also sometimes be used as short circuits to secure a make circuit connection in the main line. The break circuit face key must therefore be used as a short circuit, which involves no great difficulties, if there is sufficient power.

In constructing the face key spectacle rims are taken and arranged as shown in the cut. The nose piece contains the springs for keeping the contacts together. The key must stay rather firmly in place, so it may respond accurately to the beginnings of movements. For this purpose the key is tied with a band behind the head. Rather heavy frames, or light frames reenforced by copper wire, are best for carrying sufficient current. With good construction, the durability ought not to differ greatly from that of any other pair of spectacle frames. The subject feels more at ease and the hygienic features are more convenient, if not better, than they are in the case of keys held between the teeth. The touch stimulation key, represented in Fig. 7, does not differ in any important respect from the usual. The rate of separation of the contacts, however, is not less but greater than the rate of motion of the point touching the skin.

The sounder, represented in Fig. 8, for sound stimulation is somewhat different from the usual dropping ball apparatus. It consists of a small hammer held down against the surface it strikes by a spring. The contact of the hammer with this surface starts the chronoscope. The spring holding the hammer

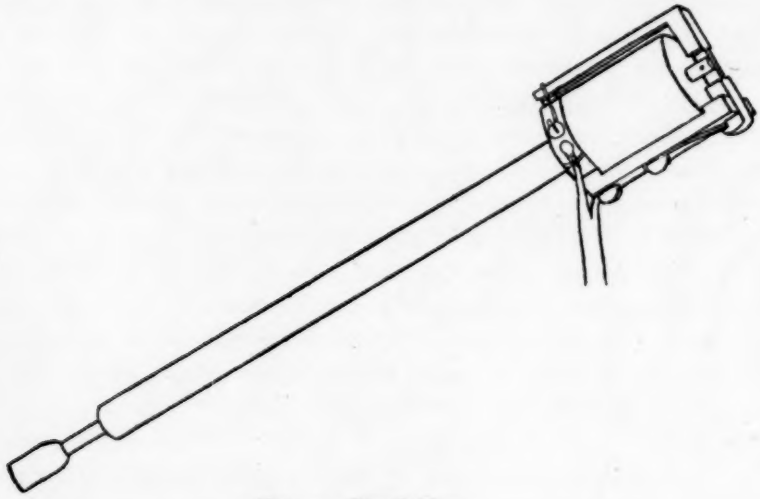

FIG. 7. Touch Key.

down should be under sufficient tension to prevent any rebound. The scale enables the experimenter to use the same or different intensities of sound stimulation, as he may wish. An attempt to arrange the scale for equal audible or equal physical units of intensity has not been made. In this respect the dropping ball apparatus has the advantage of having the ball drop with kinetic energy proportional to the height of the fall, though it is not certain that the complex sound caused by the ball striking the bridge and the bridge in turn the base is precisely proportional to the kinetic energy. For accurate work, the intensity both audible and physical of the sound from the falling ball apparatus would probably also need to be determined. The sound from the falling ball apparatus is dull, while that from the sounder here described is relatively sharp. It is proposed chiefly because of its convenience, as it furnishes accurate conditions in a small compass, except for experiments upon the

effects of varying intensities, for which it would require further graduation.

With regard to the accuracy of this type of chronoscope, the writer has made several tests at different times. Some results are reported in the article describing model no. 1. Instead of adding to these, some results kindly lent by Professor W. D. Scott, of Northwestern University, will be summarized. The

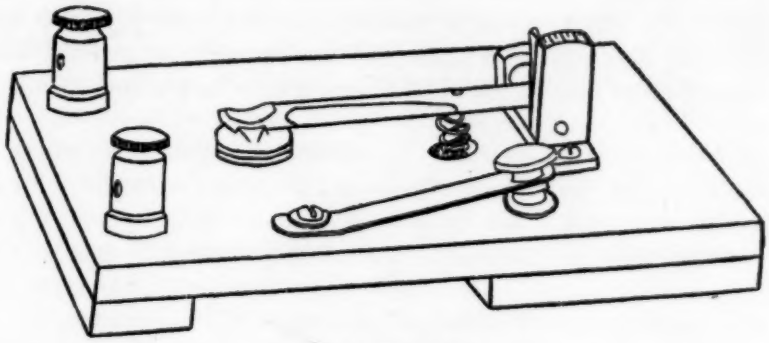

FIG. 8. Sounder.

tests were made on a chronoscope of model 2, constructed by Stoelting & Co., and were executed by Mr. Gordon Fulcher. The account of the tests points out that variations in the record may be produced by varying the current either in the escapement or the index coils; and the records giving the absolute time are obtained only with a certain adjustment of the escapement and index.

The testing apparatus consisted of two falling weights, one striking a lever starting the chronoscope, the other striking a lever and arresting the index. The possible errors of the testing apparatus appear to have been very small.

Under circumstances most favorable to the chronoscope, he obtained readings for intervals of 200σ and 100σ 'as closely identical as could be determined by the eye.' His general conclusion is that the chronoscope could be made to read to $1/5\,\sigma$. By special care in construction or by adding a certain constan to the averages, this adjustment of the chronoscope which gives the best results could be made permanent. In adjusting it so as to

secure absolute records directly, however, somewhat less uniform results were obtained. For an interval of 200 σ he obtained records of 199.9, 200, 199.8, 200.1 and 200 σ and for 100 σ he obtained 100.5, 100, 100.1 and 100.5 σ.

In dealing with records as small as a fraction of σ, the utmost precaution must be taken to avoid any disturbance. For example, the slight jar given the chronoscope by having the key of the testing apparatus on the same table with it had a determinable effect, when it was brought down sharply, and the accuracy attained in practice will doubtless be somewhat less than in these tests in which the utmost care was taken.

MENTAL PROCESSES AND CONCOMITANT GALVANOMETRIC CHANGES.[1]

BY DANIEL STARCH, PH.D.

Problem. — The purpose of this investigation was to observe and to record the changes in the resistance of the body to a weak electric current during different types of mental states and processes. The specific problems were to determine: (1) Whether all or only some mental processes are accompanied by changes in electrical resistance, (2) whether different types of mental processes are accompanied by characteristically different variations in resistance, and (3) whether the degree of intensity or vividness of a given process is accompanied by a corresponding amount of change in resistance.[2]

Apparatus. — The apparatus consisted of two electrodes, a Leeds and Northrop mirror galvanometer, and a chloride storage cell. Considerable difficulty was experienced in obtaining satisfactory electrodes. In a large number of preliminary experiments electrodes similar to those employed by Tarchanoff[3] were used, but they were discovered to be polarizable and unreliable and therefore had to be discarded. Those finally found to be satisfactory and used in all the experiments described in this paper were the Ostwald[4] calomel-normal electrodes. Thistle tubes, 12 cm. long and 3 cm. in diameter at the top and 2 cm. at the bottom, served as the vessels into which the following contents were placed: A piece of platinum wire fused into the bottom of the tube; mercury to the height of 1 cm.; above the mercury a mixture (Brei) of calomel and mercury, 1.5 cm.

[1] From the Psychological Laboratory of Harvard University.

[2] This phenomenon, frequently called the 'psycho-galvanic reflex' was discovered in 1888 by Fere and further studied by Tarchanoff in 1890. A brief résumé of contributions on this subject can be found in the article by Peterson and Jung in *Brain*, 1907, Vol. 30, pp. 153–218.

[3] Tarchanoff, 'Ueber die galvanischen Erscheinungen in der Haute, etc.,' *Archiv f. d. ges. Physiologie*, 1890, Vol. 46, pp. 46–55.

[4] Ostwald-Luther, *Physiko-Chemische Messungen*, Zweite Auflage, Seite 381.

high; calomel shaken with mercury, 2 cm. high; a porcelain sieve; cotton (supported by the sieve) saturated with a 7.45 per cent. solution of KCl. The cotton filled the vessels to the top and made contact with the skin to which they were applied. To secure uniform cleanliness, the upper layer of cotton was frequently removed and fresh cotton substituted. These electrodes were mounted in convenient wooden frames which kept them upright and also served as means of attaching them. The upper part of the frame consisted of a light horizontal board through which the electrodes projected sufficiently to make good contact with the hands or other area of the skin placed upon them. The hands were held in place by wide, flexible leather straps which were fastened to the frames. The electrodes were put in circuit with the cell and resistance coils aggregating 8,800 ohms.

In order to have the mirror as free from jars as possible, the galvanometer was placed upon a support fastened to the wall of the building. The reading telescope was so set upon a table that the scale was at a distance of 1 m. from the mirror. In this manner the scale was reflected into the telescope, and a very slight turn of the mirror would therefore reflect different parts of the scale. The sensitiveness of the galvanometer was such that a change of deflection of 1 cm. on the scale meant a change of .001 milliampere in the galvanometer. The latter was shunted by an adjustable resistance so as to regulate the amount of current that should go through it. Before each experiment the two electrodes were connected by moist filter-paper instead of the subject's hands, and the slide of the resistance was so adjusted that the deflection of the mirror was 10 cm., from 33, the zero point, to 43. Usually very little adjustment was necessary, because the cell was fairly constant, which insured considerable uniformity in the current. The cell was always connected with two Edison-Lalande cells except during the experiments.

Procedure.—The subject was comfortably seated on a chair beside a table and required to be as passive as possible by avoiding all activity except that connected with the different forms of stimuli. Usually the subject had his eyes closed

except when they were needed for the experiment, or else confined his view to some previously determined point. The palms of the hands were placed upon the electrodes and held in place by the straps passing over the backs of the hands. The electrodes were placed wherever it was most convenient for the subject, usually either on a support in front of him just above the knees, or on chairs beside him. In order to give uniformity to the condition of the skin of the various subjects, every one was required to wash his hands before the experiment.

The readings of the galvanometer were obtained by observing the scale as seen through the telescope and recording the extremes of the oscillations of the mirror. The average of two successive extremes was regarded as the determination of the deflection of the mirror from the zero point. The following is an illustration of the records thus obtained.

		Av.
33.0		
33.9	33.8	33.85
34.4	53.6	34.0
34.3	34.0	34.15
34.1	34.0	34.05
34.2	34.0	34.1
34.2	34.0	34.1
34.3	33.9	34.1
34.3	34.1	34.2
*34.3	34.3	34.3
35.2	34.7	34.95
34.8	34.6	34.7
35.4	34.4	34.9 etc.

33.0 is the zero point of the mirror before the subject's hands were attached to the electrodes. As soon as the hands were attached and the circuit completed the mirror turned to 33.9 and immediately back to 33.8, then to 34.4 and back to 33.6, etc. At the point indicated by the asterisk a stimulus was applied, and consequently the deflections were greater, which means a decrease in the resistance of the body.

Ten subjects were employed in the experiments: *B*, *D*, *F*, *H*, *N*, *P*, *R*, *Rg*, *T* and *Y*. All were members of the psychological laboratory of Harvard or Radcliffe, *D* and *P* being women. Not more than one record was obtained from a given person on one day.

Records of Normal Passivity. — The object of the first series of experiments was to obtain records from normally passive subjects. Such records would at once reveal whether the resistance would change when the subject was at rest, and would also furnish standard curves with which to compare all other records obtained when stimuli were applied.

The procedure was simple. The subject was asked to take a comfortable position on the chair and told to be as completely passive as possible. His hands were then connected with the electrodes and readings were taken for twenty minutes. Immediately at the completion of the record the subject wrote a careful introspective account of the period. One record was obtained from each subject.

The results can best be represented by curves, Fig. 1. The points in the curves are determined by the averages of the successive pairs of readings as explained above. The numbers at the left of the figure represent the scale in centimeters, 33.0 being the zero point. The letters at the beginning and end of the curves refer to the subjects. A rise in the curve means greater and a drop means less deflection of the mirror from the zero point. Or in terms of resistance a rise means a decrease and a drop an increase.

From these records it is plain that the typical passive curve runs along by small zigzags on the same general level, indicating that the resistance is practically constant under normal passive conditions. Seven of the ten curves agree on this point. The other three, *F*, *P*, and *Y*, show very distinct rises about the middle of the curves. These deviations are, however, explained by marked disturbances which occurred at the points indicated. In the case of *P* some one unexpectedly entered the room at the point marked *x*. This aroused a strong emotional state especially because the subject could not turn to see who it was. The record was therefore terminated at the end of fourteen minutes. At *x* in the curve of *Y* there was a loud disturbing noise in the adjoining room and a few seconds later the subject moved one of his hands. *F* seemed to be somewhat restless throughout the entire period. At *x*1 he opened his eyes and turned his head to look at the tower clock on a

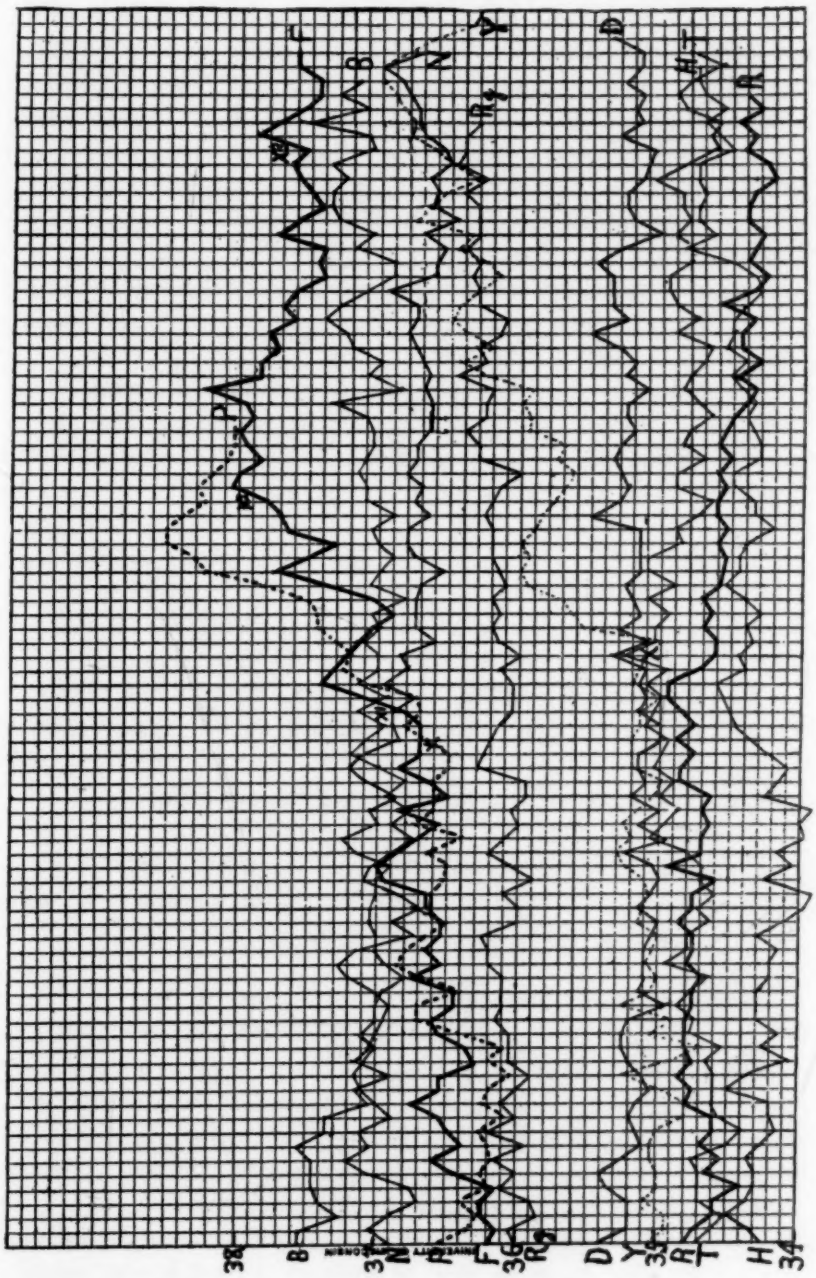

FIG. 1.

neighboring building. When it occurred to him that he should not have done this and that it was disturbing to the experiment, the whole situation seemed rather humorous to him. At *x*2 he swallowed and took a deep breath, and at *x*3 he again took a deep breath. Later experiments will show further that similar deviations in the curves are due to such disturbances. The smaller fluctuations of the curves are probably due to less marked mental changes.

The individual differences are indicated by the fact that the curves are on different levels. Apparently some individuals offer more resistance than others.

Muscular Work. — The aim in this series of experiments was to obtain records of subjects doing muscular work. The type of work desirable for this purpose was voluntary muscular work involving as little mental activity as possible. The task selected was the repeated lifting of the right knee at a rhythm chosen by each subject. The height of the lifting was about five inches, which was determined by a crossbar fastened five inches above the knee. This work was continued by each subject as long as it comfortably could be without causing too much fatigue.

The records were taken in the following way. The electrodes having been attached, the subject was asked to be passive during the first two minutes after which at the signal 'Now,' he began to lift the knee as directed before the experiment. When the work was stopped the subject again took a passive attitude and readings were continued for several minutes longer, varying in the different records from three to six minutes. Immediately after the experiment the subject wrote an introspective account.

The results are represented by the curves in Fig. 2. The beginning and the end of the work periods are indicated by short heavy lines across the curves. Two of the subjects were asked to stop the lifting of the knee, *Y* at the end of ten minutes and *D* at the end of eight minutes. The others were fatigued more quickly, *B* continuing the task for only two minutes. In no case, however, was the fatigue more than moderate.

The results indicate without exception a rise in the curve, *i. e.*, a decrease in resistance as soon as the work was begun.

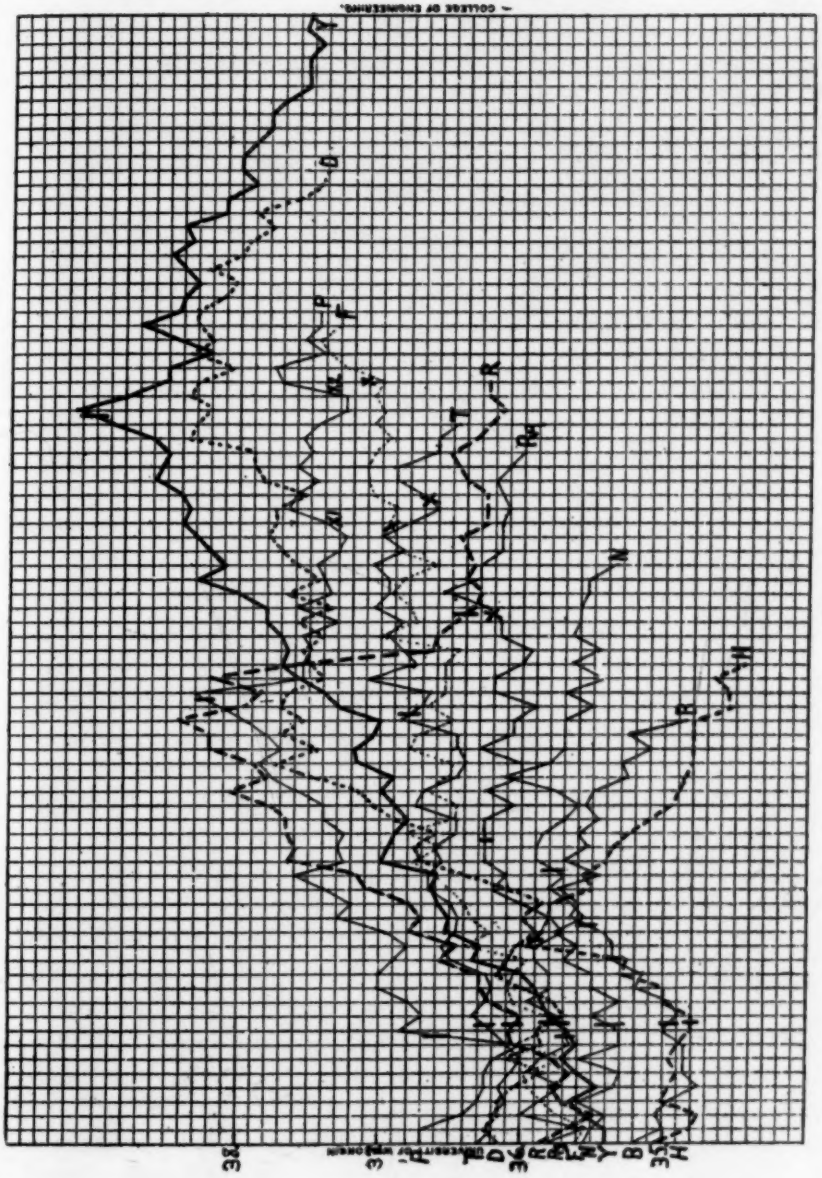

FIG. 2.

Y, the heavy continuous line, is a typical curve, rising gradually during the period of activity and dropping slowly after the cessation of work. Some curves rise very considerably above the initial passive period, for example *Y*, *D* and *R*. Two curves, *N* and *Rg*, show only a small rise. In some cases the rise is quite rapid, in others rather slow. All but three curves, *N*, *T* and *F*, show a drop in the final passive period.

The evident conclusion of these experiments is that the bodily resistance decreases during muscular work. The introspective statement of the subjects further corroborate the observation made in connection with the preceding series of experiments that the resistance is decreased by emotional excitement. For example, in the curve of *P* the subject took a deep breath at *x*1, and at *x*2 a loud noise occurred in the adjoining room. At *x* in curve *T* the subject heard someone speak which vividly recalled a certain discussion. At *x* in curve *F* the subject remarked that his right hand 'itches like sin.' At *x* in curve *Rg* the subject took a deep breath.

Mental Work. — In contrast with the experiments just described another series was undertaken to find the effect of work distinctly mental and accompanied by a minimum of muscular activity. The task selected was the effort of visual attention to objects in the indirect field. A small cross drawn on a piece of paper served as the fixation point. Twelve centimeters to the right of this was written a group of six capital letters, each one centimeter high. The task consisted in focusing the eyes upon the cross and in directing the attention at the same time to the group of letters to make out what they were. Twelve centimeters was far enough from the point of regard to make the task sufficiently difficult. No subject succeeded in reading all the letters during the course of the experiment. The sheet of paper bearing the letters was placed in a convenient position upon the table at which the subject sat. The letters were covered with another sheet of paper until they were to be used.

In taking the records the subject was asked to be as passive as possible during the first two minutes. At the signal 'Now' he opened his eyes and fixated the cross. The letters were then uncovered. The subject kept up his task of attempting to read

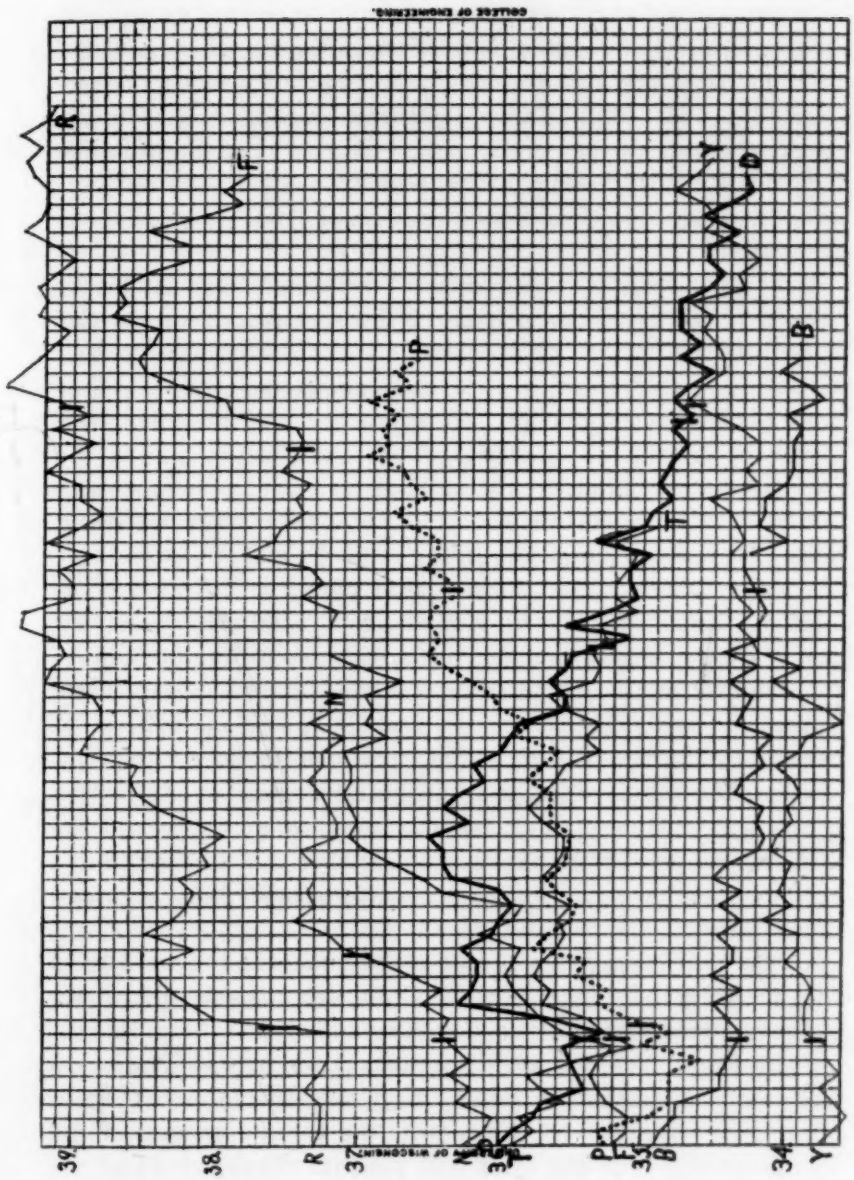
COLLEGE OF ENGINEERING.
UNIVERSITY OF WISCONSIN.
K
F
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FIG. 3.

them as long as he comfortably could. This was then followed by a passive period of four minutes.

Eight records were obtained, shown in Fig. 3. Two subjects did not succeed well in controlling the eyes and so their records were discarded. All the curves, with one exception, rise during the performance of the mental task. The curve of *B* gradually drops from the beginning. This was probably due to the subsidence of an emotional state experienced just before the experiment.

Comparing these records with the curves of muscular work, we notice the significant difference that the former do not rise as high as the latter. Quiet mental work, although performed with considerable effort, is apparently accompanied by a rather small galvanometric change. *Y*, whose curve of muscular work rises very considerably, shows a very much smaller rise in the curve of the mental work, although, as he states in the introspective account, he made a very conscious effort to perform the visual task. The conspicuous rise in the latter half of his curve may be due according to his introspection partly to the discomfort from not being able to "blow his nose." Similarly the deflection in *P's* curve may be due principally to the feeling of fatigue. This subject says: "The strain was very noticeable especially toward the end of the period . . . which caused me to be quite uneasy and nervous." *R*, whose curve also shows a higher deflection than the average, states in his introspection: "Fixation of the spot was not difficult but the attendant effort to hold the attention on the letters was very fatiguing. It involved an eye control which produced a conscious tension in both legs and arms."

The conclusion from these records, therefore, seems to be that mental activity is accompanied by a noticeable though milder galvanometric reaction than muscular activity.

Automatic Mental and Muscular Activity. — The next problem was to compare automatic muscular and mental types of activity with each other and with the voluntary types of the two preceding sections. For this purpose the repetition of the multiplication tables, either quietly or aloud, was selected. This is of course only partly automatic activity but it served

the purpose well because it could be accompanied, when desired, by equally automatic muscular activity.

The course of a record was as follows: two minutes passive, two minutes repeating the 3's quietly (or aloud), two minutes passive, two minutes repeating the 4's aloud (or quietly), two minutes passive.

The results are tabulated in Table I. The figures express in centimeters the maximum deflection during a given period of activity over the last reading of the passive period preceding it. Thus *D* shows no increase in deflection over the first passive period when repeating the 3's quietly, but the loud repetition of the 4's is accompanied by an increase in deflection of 1.45 cm. over the second passive period.

TABLE I.

	3's Quietly.	4's Aloud.
D	.00 cm.	1.45 cm.
H	.05	.20
N	.15	.55
F	.45	.45
T	.20	.60
Y	.15	.75
Av.	.17	.67
	3's Aloud.	4's Aloud.
P	.85 cm.	.65 cm.
B	.45	.45
Av.	.65	.55

The interesting fact brought out in this table is that habitual mental activity is accompanied by very little change in the galvanometric readings, only .17 cm. on the average, while similar activity accompanied by automatic muscular activity produces a distinct rise, on the average .67 cm. To show that this difference was not due to the particular table repeated nor to the succession of repeating quietly in the first period and aloud in the second period, the last two subjects repeated both 3's and 4's aloud. In each case a distinct rise is present, 65 cm. and .55 cm. Apparently the difference was due to the additional exercise of the muscles involved in speaking.

In comparison with the preceding series of experiments we

notice that automatic mental activity produces less change than voluntary mental activity (visual attention). The maximum increase in deflection in the latter was nearly 3.00 cm. (*R's* record), while in the former it was only .45 cm. The voluntary muscular work of lifting the knee is entirely different and exercises much larger muscles than does the loud repetition of multiplication tables, so that the two can not well be compared. It seems, however, that voluntary muscular activity produces greater galvanometric changes than automatic muscular activity.

Emotional States: Stimuli Unexpected.— During the experiments thus far described it was frequently observed that emotional experiences were particularly effective in producing deflections. This was suggested again and again by the disturbing incidents. The remaining experiments were therefore devoted to the study of various types of emotional states.

In the first group of experiments the stimuli were unexpected. The subject was told to assume a passive attitude and that a record of fourteen minutes would be taken. During the course of the record an electric bell concealed under the table was rung three times, each time for five seconds. The ringing occurred at the end of the second, sixth and tenth minutes. These points are indicated in the curves by short, heavy cross lines, Fig. 4.

Almost without exception each ringing of the bell is followed by a distinct rise of the curve. *Y's* curve is a typical illustration. In connection with this record the following quotation from his introspective account is of interest.

"I was much startled when the bell first sounded and for a moment experienced vivid emotion. I suspect that my heart beat was markedly influenced but I did not note it particularly. I noticed that my rate of breathing increased when the bell sounded the second time. The second and third ringings did not surprise me but they stimulated me strongly and certainly produced physiological changes."

Rg, whose curve indicates smaller deflections than the record of any other subject, says the following in his introspection.

"I was conscious of very little, if any, emotional reaction from the bell at any time. There may have been a momentary start

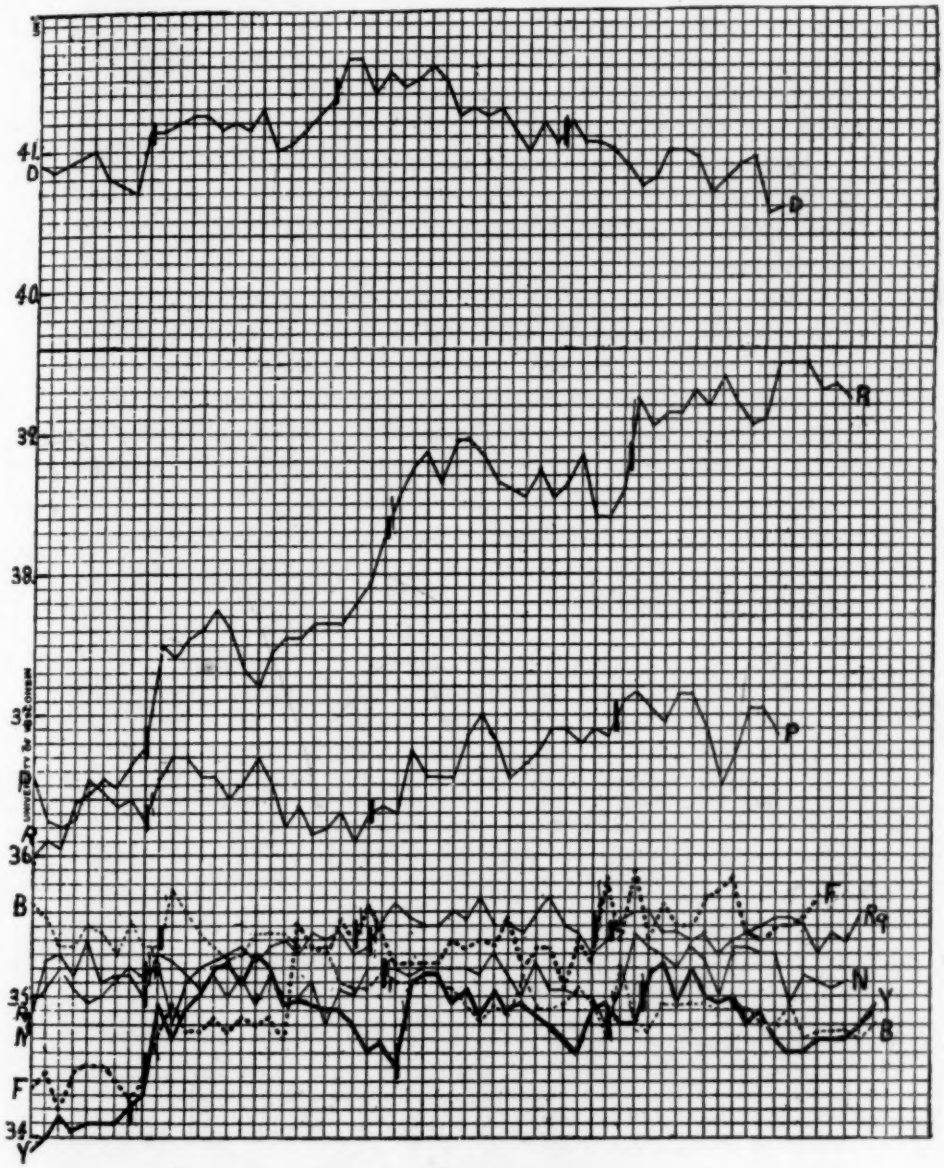

FIG. 4.

but it was immediately inhibited. I should place the reaction as very weak. I was not conscious of any change in heart beat or in breathing. I am accustomed to a large house with an electric bell system and annunciator, and therefore am used to bells at all hours, day and night."

In order to determine more accurately whether the intensity of the emotion is accompanied by a corresponding amount of deflection, the subjects were required to estimate as accurately as possible in their introspective accounts, the intensity of each emotional experience resulting from the ringing of the bell. The following arbitrary scale was adopted: no emotion, weak, medium, strong. All the records are tabulated in Table II., showing the estimated strength of the emotion and the corresponding deflection above the last reading preceding the ringing. Thus in curve *Y* the last reading before the first bell was 34.2 and the maximum reading following the ringing was 35.3. The difference, 1.1, is the figure tabulated. The figures show a fairly close relation between the amount of deflection and the intensity of the emotion.

TABLE II.

	First Bell.	Second Bell.	Third Bell.
B	Medium, .40	Weak, .15	Weak, .15
D	Weak, .10	Medium, .30	Weak, .15
F	Strong, .60	Strong, .25	Medium, .65
N	Strong, .30	Weak, .00	Strong, .65
P	Weak, .45	Weak, .45	Weak, .25
R	Weak, .85	Medium, .65	Strong, .80
Rg	Weak, .10	Weak, .30	Weak, .20
Y	Strong, 1.10	Medium, .70	Medium, .45
Av.	.49	.35	.41

Average of all described as weak, .25.
Average of all described as medium, .52.
Average of all described as strong, .62.

Emotional States: Stimuli Expected. — The next series of records was obtained in a similar manner with the exception that before each bell two warning signals were given. The subjects were told that the signal 'Ready' would be given thirty seconds, and the signal 'Now' two seconds, before the ringing of the bell. The signals were given so that the ringing would occur at the end of the second, sixth and tenth minutes.

Here, however, another variation was introduced. The bell was rung only at the end of the second and sixth minutes. The third time the signals were given as before but the bell was not rung. This, of course, was unknown to the subjects. The aim was to see what the effect of expectation, without the occurrence of the stimulus, would be.

The results are presented in Table III. which is compiled in the same manner as Table II. No records were obtained from four subjects.

TABLE III.

	First Bell.	Second Bell.	No Bell.
B	Strong, .40	Weak, .00	Strong, 1.80
D	Medium, .70	Weak, .20	Medium, .50
P	Strong, .45	Medium, 1.85	Weak, .85
R	Medium, .65	Strong, .25	Weak, .00
Rg	Weak, .25	Weak, .10	Weak, .30
Y	Weak, .05	Weak, .25	Weak .50
Av.	.42	.44	.66

Averages of all described as, weak, .25 ; medium, .92 ; strong, .72.

The average deflections after the first and second ringings preceded by the signals are practically the same as in the foregoing records where the subjects had no inkling of what was coming, .42 cm. and .44 as compared with .49, .35 and .41. The reason for this probably lies in the fact that the warning signals affected the different individuals in quite opposite ways. In some, the emotional excitement seemed to be heightened through the signals so that in several instances a deflection occurred immediately after the first signal. In others, the signals brought about a calm preparation for the sound. As an illustration of the former the following quotation from *P's* introspection may be cited.

"Just after the signal 'Ready' I began to be conscious of my breathing. It seemed more hurried. I had the feeling as if I needed to take a long breath but couldn't. At the same time I became conscious of the beating of my heart and of a tension in the muscles. These symptoms became more marked, reaching a crisis just after the signal 'Now.' When the bell rang I 'started' very slightly but I had the consciousness of a sudden and marked change. The emotion was strong."

As an illustration of the second class of subjects, *Y* may be quoted.

"The bell caused no disturbance. There was a relaxation immediately for I had been expecting it on account of the signals. If any emotion was aroused by the bell it was one of mild satisfaction and amusement. I do not know that either my heart beat or my respiration was influenced. The influence of the bell was even less the second time. I was not disturbed by its failure to come the third time but I was again amused."

The third stimulus of giving the signals without the actual ringing was followed on the average by a greater deflection than the actual ringing, .66 cm. as compared with .42 and .44. The emotional excitement caused by the omission of the bell was in most subjects quite vivid and usually amusing. *B* wrote the following statement:

"The 'Now' signal, preceding the omission of the bell, resulted in a considerable alertness and a mental bracing against the coming sound. This resulted, I think, in deeper and longer breathing. When the sound did not come, tension grew rapidly greater until I realized the situation, and the joke of it produced considerable amusement, which, however, I tried to suppress. It went and came intermittently several times. The breathing became shallow and quick. Then relaxation and drowsiness returned."

These introspective statements correspond on the whole very closely with the extent of the deflections. *P*, who reports an intense emotional experience, shows very large deflections, and *B's* description of the failure of the bell also correlates with a large rise, 1.80 cm. On the other hand *Y*, who was little disturbed by the stimuli, shows very small galvanometric changes. Too much significance, however, should not be attached to the figures because of the rather wide distribution. For example, those described as 'medium' range from .50 to 1.85. This latter reading accounts for the fact that the average of the 'mediums' is larger than the average of the 'strongs.'

Emotional States: Unpleasant Stimuli. — To determine the effect of unpleasant stimuli, records fourteen minutes in length were obtained during which three stimuli were applied by an

assistant, each one for fifteen seconds, at the beginning of the third, seventh and eleventh minutes respectively. The first stimulus was an unpleasant odor, the second was a spring clamp attached to the lobule of the left ear, and the third was a succession of needle pricks on the back of the left wrist.

The deflections produced by these stimuli are given in Table IV.

TABLE IV.

	Odor.	Clamp.	Needle.
B	Weak, .05	Medium, .30	Weak, .00
F	Medium, .60	Medium, .55	Weak, .25
R	Weak, .45	Medium, .40	Medium, .20
Rg	Medium, .35	Medium, .50	Medium, .55
T	Medium, .50	Medium, .45	Strong, .45
Y	Medium, .55	Strong, .85	Strong, .60
D	.40[1]	.25	1.05
P	.40	.40	.60
Av.	.41	.46	.46

The stimuli used were of course not equally unpleasant to all the subjects. The odor was quite disagreeable to some and practically indifferent to others. Nevertheless, the subjective gradations of unpleasantness agree very closely with the readings. The average deflection for 'weak' is the smallest, and for 'strong' the largest.

Reading Informative and Humorous Passages.—Four records were obtained to compare the effects of reading two different kinds of materials. One was a description of political events, the other was a short humorous story, each containing about seven hundred words. Both were read quietly by each subject during the course of a record. One was started at the beginning of the third minute and the second was started at the beginning of the eighth minute in the record. The interval between the two readings varied from one half to four minutes, depending upon the rapidity of reading.

The results in Table V. indicate that both readings were accompanied by deflections. The 'humorous' reading, however, produced larger deflections than the 'informative,' .42 cm. and .29 respectively. The explanation probably lies in the fact

[1] By mistake *D* and *P* failed to write introspective accounts.
Averages of all described as, weak .19, medium .45, strong .63.

that the former reading was accompanied by a stronger emotional tone.

TABLE V.

	Informative.	Humorous.
R	.20	.25
Rg	.25	.40
P	.35	.50
V	.35	.55
Av.	.29	.42

Summary of Results. — 1. During undisturbed passivity practically no galvanometric changes occurred.

2. All the different types of mental processes produced by the various stimuli were accompanied, without exception, by galvanometric changes.

3. Some mental processes were characterized by very much larger deflections than others. Emotional processes and muscular activity produced the widest deflections, while habitual mental activity and the process of visual attention produced the least deflections. Quiet mental activity even when involving considerable effort produced small galvanometric changes. It therefore seems to follow that those types of mental processes which are accompanied by the most distinct and widespread physiological changes produce the largest deflections, such as, muscular activity in lifting the knee; strong emotions accompanied by a 'start' or 'shock,' halting and quickening of respiration, muscular tension, etc.

4. The degree of intensity of emotional experiences corresponds very closely with the amount of deflection. Combining Tables II., III. and IV., the average deflection of all emotions rated as 'weak' is .23 cm., of all rated as 'medium' .63, and of all rated as 'strong' .66.

This investigation has dealt primarily with the determination of amounts and types of galvanometric changes. Whatever the ultimate cause of these changes may be, whether it be in the resistance of the skin or in the variation of other functions, the results here set forth will not necessarily disagree with either explanation.

THE DEVELOPMENT OF RIGHT-HANDEDNESS IN A NORMAL INFANT.

BY HELEN THOMPSON WOOLLEY.

In making some tests on color vision during the seventh month of a normal infant's life, the method used was that of presenting two discs laid side by side directly in front of the infant, and recording the one selected. The hand used in picking up the disc, and the position of the disc chosen were also recorded. The same data were kept in making a similar series of tests with a wooden square and circle. In the color tests, the discs were all placed within easy reaching distance; but in the series with the square and circle, the distance was varied from three to ten inches, and the effect on the hand used recorded. The color tests were begun at the beginning, and those with the square and circle at the middle of, the seventh month. Both series were discontinued at the close of the seventh month, for reasons given in reporting on the color tests. The number of color tests included in this report is greater than that in the tables on color choice, because some series which were invalidated for color for one reason or another, were still significant with reference to the use of the hands.

The few instances in which the child picked up one object in each hand were discarded. For the color series, where the distance remained constant, the hands were used as follows: right hand, 206 times; left hand, 194 times; both hands, 68 times. The difference in the use of the right and left hands for the entire series is not great enough to be significant, but in reviewing the chronological order, it is interesting to note that the days on which the use of the left hand predominated, were all, with one slight exception, during the first week of the month. In fact for the first week, the left hand was used more frequently than the right, but after that, the right hand predominated steadily.

The experiment of testing the effect of the distance of the

object on the use of the hands in grasping, was first tried by Professor Baldwin with an infant in its ninth month. His observation that reaching called out the use of the right hand almost exclusively, at a time when little if any distinction in the use of the hands could be detected in activities not requiring effort, was easily verified in the case of this infant in the seventh month. A series of informal tests showed the preference for the right hand in reaching, so uniformly that formal experiments on the point were scarcely necessary. However, the following series of 70 tests was carried out. The distance of the square and circle was measured from the center of the object to the child's body.

Inches.	Right.	Left.	Both.
3	7	13	0
5	4	8	2
7	13	7	0
8	10	0	0
10	6	0	0

Seven inches is the distance which just required reaching, while ten inches required so much effort that the child was loath to make it. A larger series of results would doubtless have produced some instances of the use of the left hand in reaching for objects more than seven inches away, but I feel confident, in view of the uniform results of informal tests, that a longer series would not have changed the trend of the table. During the same period I found that she also used the right hand for catching a swinging object, and for picking up an orange, a very difficult accomplishment at that age.

After the beginning of the eighth month I have no experimental material, but I have notes on the normal use of the hands. During the seventh month, the period of the tests, my general observations showed no signs of right- or left-handedness. I should have said that none existed, were it not for the experimental evidence. The same holds true of the eighth month. Early in this month she discovered how to snap the rubber string attached to one of her balls. She held the ball down with one hand, and snapped the string with the other; an operation in which a right-handed adult would be sure to make

a distinction in the use of the hands. The child made none. It seemed a matter of indifference whether she held the ball with the right hand and snapped the string with the left, or vice-versa. Of course an accurate count might have revealed a difference which was not apparent to inspection.

A little after the middle of the eighth month, the child began waving 'Bye-Bye.' She learned to do it in connection with starting for a ride, an experience which gave her great joy. In taking her out to her cab, the nurse always carried her on the left arm, leaving the child's left hand free, and as a result, she learned to wave 'Bye-Bye' with the left hand. A few days later we noticed that if her left hand was held, she refused to wave, but did so joyfully as soon as the hand was released. Early in the ninth month, she would wave 'Bye-Bye' with the right hand if the left were held, but still used the left hand if it were free. My subsequent notes on the point are meager, I regret to say, but I know the general course of events. Somewhat later she passed through a stage in which she used either the left hand or both hands in waving, but never the right hand alone. Then gradually she began using the right hand occasionally, and by fifteen months, she had ceased using the left hand, and waved habitually with the right.

But long before her right-handedness had conquered habit in the matter of waving 'Bye-Bye,' it was perfectly evident in other activities. Toward the close of the eighth month, she began playing ball. She had a ball so large that it was a continual matter of surprise that she could make it stick in one hand. Sometimes she picked it up with both hands, but during the first days she always threw it with the right hand alone. After about a week of ball playing, she began using the left hand, or both hands occasionally in throwing, but the right hand has retained its ascendancy without a break.

During the ninth month, right-handedness began to be apparent in her ordinary activities, and by the end of the month I have the note 'evidently right-handed even to casual observation.' When in her seventeenth and eighteenth months she began using spoons and pencils, she used the right hand almost as exclusively as an adult, and was awkward when she tried

the left hand. No attempt was made at any time to teach the use of the right hand. The only factor in her surroundings of which I was aware, that might have influenced the process — that of the arm on which she was habitually carried — favored the left hand, as I have pointed out. But even the impetus given to the use of the left hand by this factor, as shown in waving 'Bye-Bye,' was soon overcome by her native right-handedness.

In recording which of the discs or forms was taken, it soon became apparent that regardless of the hand used, the right-hand position possessed an independent attraction for the child. In the selection of the colors, where the right hand was used 206 times and the left 194, the right-hand *position* was selected 285 times, and the left 183. The difference is even more marked in the case of the square and circle, where the material itself was indifferent. Out of 70 choices, 56 were for the right-hand position and only 14 for the left. The fact that the right hand was the one used for reaching, and that in this case some of the series were presented at reaching distance, tends to increase the choice of the right-hand position in this case, but even so, the right-hand position has an independent attraction, for it is chosen more times than the right hand is used. The right-hand position was taken 56 times, while the right hand was used but 40 out of the 70 times.

I must confess myself at a loss for an explanation for this preference for the right-hand position. It could not have had to do with the child's posture, or with her relation to the light, for those factors were varied from day to day. The tests were not all made in the same room, and the child sat sometimes in a high-chair, sometimes on a couch, and sometimes on the floor. The only requirement was that she should be in an easy position, with both arms free to move. The only suggestion which seemed at all probable was that it might be conditioned by her eyes, though as far as I could judge, or could test them, her eyes seemed not only normal, but unusually good. They were very well coördinated at an early age, and gave more evidence of distant seeing than is usual at so young an age.

So far as their application to theory is concerned, the tests are one more proof of the already accepted view that right-

handedness must be a normal part of physiological development, not a phenomenon explicable by training. The preference for the right-hand position, in excess of that for the use of the right hand, suggests a query as to whether the eyes could play a rôle in the development of right-handedness, but the query is scarcely worth making so long as the observation is an isolated one. The theory that the speech center and the neighboring one for the right hand in the left hemisphere are associated in development, received some support in this case. The period when the tests first show a preponderating use of the right hand in picking up the colors (the middle of the seventh month), is just the one when the child began to babble syllables. Before that, the variety of sounds she made had been small. But the early development of a decided right-handedness (ten months) has not been accompanied by an early acquisition of speech. Though she said her first word at about ten months, she has acquired them very slowly, and has but fifteen or twenty words, many of them very indistinctly pronounced, at eighteen months.

STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF THE UNIVERSITY OF CHICAGO.

The Autokinetic Sensation.

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This paper presents some of the results of a series of observations designed as preliminary to a more extended and detailed investigation of the autokinetic illusion. This subject has been selected by a graduate student of this department for a doctorate thesis. As a consequence, a separate publication of these results was deemed advisable. Historical references and discussions of explanatory theories have been omitted as much as possible.

The autokinetic sensation refers to the illusory movement presented by a small light of weak intensity when fixated in a dark room. Our tests are designed especially to determine the conditions governing the direction, speed and uniformity of these movements. Many observations of previous investigators have been confirmed during the progress of the experiments, but these results will not be mentioned except where modifying statements need be made. Four subjects, *C*, *A*, *W* and *F*, were used at times. At least two subjects were used in every test.

A. Extent and Velocity.

Greater extent and velocity of movement were observed than had been formerly reported. Charpentier[1] states that the illusion may attain a length of 30° or more. Subject *C* reported illusions of at least 65° in extent. These maximum results were obtained under conditions of marked ocular fatigue and constrained eye position. Often the light would move upward to such an extent that it would appear almost vertically above the head. Under conditions of previous constrained eye position (see Sec. F.), the light moved with an apparent velocity of

[1] 'Sur une illusion visuelle,' *Comptes rendus*, CII.

15°–20° per second, giving the impression of a sky rocket or a rapidly moving shooting star.

B. Uniformity of Occurrence.

One subject, *F*, out of the four did not experience the illusion under any condition. The fact that some persons cannot obtain the phenomenon has been reported but no idea has been given as to the percentage of such cases. The fact that the direction, rapidity, regularity and extent of the movements vary with individuals was confirmed. An individual treatment of most of the results is thus rendered necessary.

C. Types of Illusion.

The illusion may occur under three typical conditions: (1) The point of fixation remains with the light and participates in the illusory movement. (2) The point of fixation apparently remains stationary and the light moves away from it in some direction. (3) A combination of the above two types occurs. Both the light and the fixation point participate in the illusion, but unequally. The fixation often lags behind the light, especially for constrained positions of the eyes in the socket.

The first type of movement is the only one specifically mentioned in the literature. The second type could not be obtained by subject *W*. Observers *A* and *C* can obtain any type of movement at will.

The second type of movement differs from the first in several respects. Its extent is less under similar conditions. The maximum amount of movement observed was 20°. The average extent was approximately 10° in our tests. The amount varies with individuals, however. Its rapidity is much slower than that of type I., being barely perceptible in many cases. Its direction is more uniform during any one observation, and more constant for successive tests for the same eye position. This statement is especially true for the more central eye positions. Its velocity tends to be jerky and discontinuous as contrasted with the relatively smooth, flowing and continuous motion of the first type. The illusory movement finally stops, the light remaining stationary at some secondary position. This phe-

nomenon never occurred in the first type for our subjects, though it has been reported in the literature of the subject.

D. Appropriate Eye Movements.

No appropriate eye movements occur in the first type of illusion. By an appropriate eye movement is meant one whose length approximately equals the extent of the illusion and whose speed and direction bear some constant relation to the velocity and direction respectively of the illusion. Slight irregular twitchings of the eye are of course present, as one might readily infer from the recent photographic work upon fixation and eye movement. The eyes are thus relatively motionless during the illusion and the apparent movement of the fixation point is an illusion.

Appropriate eye movements do occur in illusions of the second type. The eyes move to the same extent as the light but in the opposite direction. The fact that the fixation point appears to remain stationary is an illusory phenomenon.

The position of the point of fixation in relation to the light thus indicates the relation of the light to the eye. The light is foveally perceived when the fixation point and the light coincide in position, and it is peripherally perceived when they do not coincide. The apparent distance of the light from the fixation point indicates with some degree of accuracy the extent of the deviating eye movement. The apparent direction of the light from the fixation point indicates in a large majority of cases the general direction of the deviating eye movement. Subject *A* reported in one illusion of the second type that the light had moved upwards and to the right, *i. e.*, the fixation point appeared to be situated below and to the left of the light. As a matter of fact the eyes had moved straight to the left.

This question as to the presence or absence of appropriate eye movements as a conditioning factor of the illusion has been a subject for some diversity of opinion. The writer[1] assumed the existence of such eye movements on the basis of a striking similarity between this illusion and that due to eye closure. Charpentier[2] argues against the presence of eye movements.

[1] Psych. Rev., Mon. Sup., Vol. VII., p. 94.
[2] *Ibid.*

He found that he could control the direction of the illusion to some extent by attending to some peripheral position while still maintaining fixation of the light. The illusion is deflected in the direction of the peripheral attention. Charpentier contends that any eye movement under the conditions would be directed toward the position of attention, *i. e.*, would possess the same direction as the resulting deflection of the light. Conditioning eye movements are thus impossible because their direction should be opposite to the resulting deflection according to known principles of psychological optics.

After the light had moved some distance, Bourdon[1] rotated the eyes back so as to fixate the original fixation position and then suddenly illuminated the room. It was found that the eyes were directed away from the light to the extent of the voluntary rotation. Consequently, the light must have been foveally perceived before the rotation and no eye movement was present during the illusion.

Our conclusions are based upon three kinds of experiment, all of which gave uniform and consistent results. (1) Bourdon's method of turning on the illumination of the room during the illusion was used. This was often suddenly done by an assistant at a time when the observer was not expecting it. Invariably, the eye was found to be fixating the light in the illusion of the first type. In the second type, some secondary position was fixated. The relative position of the fixation point and the light during the illusion was generally found to be the same as that obtaining after the room was illumined. In one case previously mentioned, there was a marked discrepancy between the directional relation of the fixation and the light in the two conditions of observation. (2) The negative after-image method was used. The observed light was 1 cm. square. Around this was placed strips of colored paper 1 cm. wide, forming a square 3 cm. in dimensions. The light, surrounded by the colored strips, was fixated with full illumination of the room until a strong negative after-image of the colored strips had had time to develop. The illumination was now turned off, only the light remaining visible. During the course of the

[1] *La Perception visuelle de l'espace*, p. 333 ff.

illusion the negative after-image developed and disappeared. In illusions of the first type the after-image remains with the light and participates in the illusion. With the second type, the after-image appears motionless while the light exhibits movement. In every case, the after-image is located at the point of apparent fixation. In the first type there are slight relative movements of the light and after-image indicative of small irregular movements of the eye-ball whose significance will be discussed later. (3) The eye was also directly observed during the illusion by an assistant. The subject's head was held by a mouth-bit head-rest. Before one eye was placed a small wooden frame over which was stretched a series of horizontal and vertical threads 3 mm. apart. The assistant was seated to one side and in front of the subject, a second head-rest being used to aid in accurate observation. While the room was illumined, the subject fixated the light and the assistant sighted through the system of threads at some distinctive mark on the eye-ball, *e. g.*, the line of demarcation between the iris and the sclerotic. The assistant illumined the eye observed by means of an electric flashlight whose light had been diminished in intensity and narrowed in area. This spot of light illumined the eye-ball sufficiently for accurate observation, but its position and intensity were such as not to destroy the illusion. The room was now darkened, and the eye was observed during the course of the illusion for as long a time as desired. Two observers and two subjects were used. In illusions of the first type, no movements of the eye-ball other than irregular spasmodic twitchings were observed. In the second type corneal movements were always present, whose direction, speed and extent always bore some definite relation to the corresponding characteristics of the illusion. It is to be recalled that the illusions of this type are slow, uniform in direction, and that the illusion finally stops, the light remaining in some secondary position. The conditions are ideal for the corneal observations. Corneal movements of 3–4 mm. in extent and of various directions were observed.

E. Influence of Eye Position during the Illusion.

The position of the eyes in the head during the illusion is a determining factor. The strength of this position factor and the kind of influence it exerts vary with individuals. It may modify the occurrence, the length, the direction and the velocity of the movement.

Its most marked influence was upon the direction of the illusion. Any position tended to cause the illusion to move in the same general direction as that of the illusory movements due to winking for the same eye position.[1] This was true in a general way for three subjects studied. A different result might be obtained with other subjects. The uniformity of the direction during any one movement is much greater for some positions than for others. The direction of the illusion for a series of tests in the same position is more uniform for some positions than for others.

One subject could obtain the illusion only for certain eye positions.

The extent of movement possible varied with eye position, but the influence of any position in this respect was an individual variant.

The speed of the movement seemed to vary slightly according to the position of the eye, the effect being more noticeable for some observers. The uniformity of the velocity during any one illusion and for a series of illusions with the same position varied markedly according to the positional factor.

The subject's head was held stationary by a mouth-bit headrest. The wall of the room was used as a background. Two constant eye positions were determined, the primary position and the zero points.[2] The light was placed at various positions on the wall, whose direction and distance from the primary position and zero points were known. Tests were made for each position for a number of days in succession. The direction of the illusion was plotted on a piece of paper immediately after the test, and its various characteristics as to speed, uniformity and extent of movement were noted.

[1] Carr, 'Visual Illusion during Eye Closure,' Psych. Rev., Mon. Sup., Vol. VII.

[2] Positions where no illusion occurs during eye closure.

Observer *C* performed 132 tests on 11 fixation points for the first type of illusion. There was a marked tendency for the light to move toward the periphery of the field. The direction of the illusion is thus different for the various positions of the eye in the head. The peripheral component predominated in 88 per cent. of the tests. This peripheral tendency increased with the distance of the light from the center of the field. The average percentage for all positions within 30° from the center was 75. Outside of the 30° zone the average percentage was 95. For extreme fixation positions the percentage was 100.

For a series of tests for the same position taken on successive days, the direction may vary within certain limits. These limits of variable direction decrease in proportion to the distance of the fixation position from the center[1] of the field. Near the center the limits are as high as 80°. This amount decreases to 43° and 15° for positions situated 15° and 30° respectively from the center. Outside of the 40° zone the limit of variability is practically *nil*.

The rapidity and extent of the movements are as a general rule greater for extreme peripheral positions. The speed and direction of any movement are more constant and uniform for peripheral positions. Inside of the 30° zone the direction and speed of the movements are highly variable from time to time. The motion is jerky, erratic and aimless in character.

A peripheral direction obtained for the illusions of the second type, the eye movements being directed toward the center of the field. For peripheral positions the movements were longer, and their direction and velocity were more regular.

The results of subject *A* are similar to the above. A total of 175 tests upon 17 eye positions were taken. A peripheral tendency was present in the majority of cases. This tendency increased in proportion to the eccentricity of the fixation. The percentages were 55, 73 and 97 for the distances of 7, 15 and 30 degrees respectively from the zero points. The limits of variability for successive tests in the same position decreased

[1] The center of the field usually refers to the primary position. It was impossible to determine accurately the functional center, *i. e.*, that position whose directional influence upon the illusion is *nil*. It seemed to lie somewhere between the primary position and the zero points.

with the distance of the position from the center. Approximate constancy of direction obtained outside of the 35° zone. Inside of this zone, the rapidity was relatively slow, the extent small, and the velocity and direction highly irregular. The peripheral direction obtained for illusions of the second type. The length and regularity of speed and direction varied with the eccentricity of the fixation position.

Both of the above subjects possess zero points, and the directions of the illusory movements due to eye closure generally possess a marked peripheral component. This peripheral directive tendency also obtains for the autokinetic illusion, and the strength of the position factor increases with the eccentricity of the position for both kinds of illusion.

With subject *W*, the illusion moved upwards in every case except one. The position of the eye in the head modified the direction slightly. The movements were slightly inclined to the right for all positions in the right half of the field. A leftward tendency was noticeable for positions in the left half of the field. In the lower half of the field, no illusion could be obtained in 50 per cent. of the trials. In the upper half of the field the movements were much longer and faster than in the lower half. The directions of the autokinetic illusion are similar to those of the winking illusion for the subject. No illusion of the second type could be obtained.

F. Effect of Previous Eye Position Upon the Illusion.

An eye position not only exerts a characteristic influence upon the illusion while the eye is in that position, but it leaves an after-effect which modifies the direction and velocity of the illusion in a characteristic way for subsequent eye positions. The behavior of the light in any position thus may be a function both of that position and previous eye positions.

The *duration* of the after-effect varies between zero and one minute, and it is a function mainly of the distance of the position from the center of the field and the length of time the eye maintained the position. To a slight degree it is also a function of the direction of the position from the center.

The *directional* effect of a previous fixation position is a

function of the distance and direction of that position from the center of the field. The field of regard may be divided into zones, an inner and outer. Any position '*a*' in the inner zone tends to make the illusion for subsequent positions move in the same direction as that of '*a*' from the center. Any position '*b*' in the outer zone tends to make the illusion for subsequent positions move in a direction opposite to that of '*b*' from the center of the field. This opposite direction of movement is quite rapid and is always followed by a slow return movement. The directional effects are in no way dependent upon the duration of the original fixation.

The effects upon *velocity* are a function mainly of the distance of the position from the center and the duration of the fixation. To a slight degree it is a function of the direction of the position from the center.

The after-effects of a position are thus neither similar nor antagonistic to the effects of that position during the illusion (see previous section).

The above generalizations are based upon two series of tests upon subject *C*. They are not to be regarded as possessing any universal validity. The light was placed in the center of the field where the effect of the position factor is at a minimum. The general direction of the illusion at this position was determined in a series of five successive tests at the beginning of each day's experimentation. These directions furnish the norm for comparison. During full illumination of the room, the observer was asked to fixate some peripheral position for a definite period of time determined by a stop watch. At the end of this period, the assistant suddenly turns off the illumination. The subject is directed to rotate the eyes and fixate the light immediately upon the darkening of the room. A series of seven positions 30 cm. apart in four directions from the central light were chosen. The distances of these positions from the center will hereafter be expressed in angular terms in reference to eye as the spherical center. Each position was fixated for seven different periods of time, varying from a second up to 2 minutes. This makes a total of 196 tests. This whole series was repeated. The direction of the movement was plotted

immediately after the test. These directions were compared with the normal direction for the central position.

As to the after-effects of position, the field may be divided into two zones, an inner and an outer. The inner zone is elliptical, the shorter axis being the vertical. The lengths of the two axes are approximately 45° and 60°.

Previous fixation of a position in the inner zone deflects the light to some extent in the direction of that position, provided any influence is present. Fixation of a spot 23° to the right or left of the light results in a deflection of the illusion toward the right or left respectively. This is termed an illusion in the *same* direction. An effective fixation of a position in the outer zone produces at first a rapid movement directed away from that position. This is followed by a slow return movement in the same direction. Fixation of a position 40° above the center produces at first a rapid downward movement which is succeeded by an upward movement. This is termed an illusion of the *opposite* direction to distinguish it from the effects of positions in the inner zone. The influence of the outer zone is more pronounced and characteristic than that of the inner zone. It completely determines the direction of the illusion. This direction is constant for successive trials in the same position. Positions in the inner zone simply modify the illusion in a general way. There is no constancy for successive trials, a pronounced variable factor being present. Other effective influences are present besides that due to previous position. Thus the position leaves an after-effect which modifies the direction and velocity of the illusion for a central position.

The distance of 30 cm. between the positions was chosen arbitrarily. This gradation is too large to admit of any accurate delimitation of the zones. In the horizontal the directive results were the same at the 29° 45′ position and the opposite at the 40° 30′ position. At the 35° 30′ position both tendencies were present, one or the other being predominant at times, or the two forces neutralizing each other. For this reason the 35° 30′ position has been chosen as the horizontal limit. In the vertical the directive results were always the same for the 23° position and opposite for 30° position. The zonal limits are

evidently somewhere between these two values. The same results were obtained in both series of tests.

The occurrence, velocity and duration of the after-effect depend upon the length of time the position was fixated. The duration of the fixation exerts no directive influence, however. These results for horizontal fixation points are represented in Fig. 1. The ordinates represent the duration of the fixation in sec., and the abscissæ represent the distance of the position from the center in degrees. The dotted vertical line through the 35° 30′ position represents the boundary between the two zones. (1) There is a minimum duration of fixation necessary to secure any result, and this period decreases with the eccentricity of the fixation position.

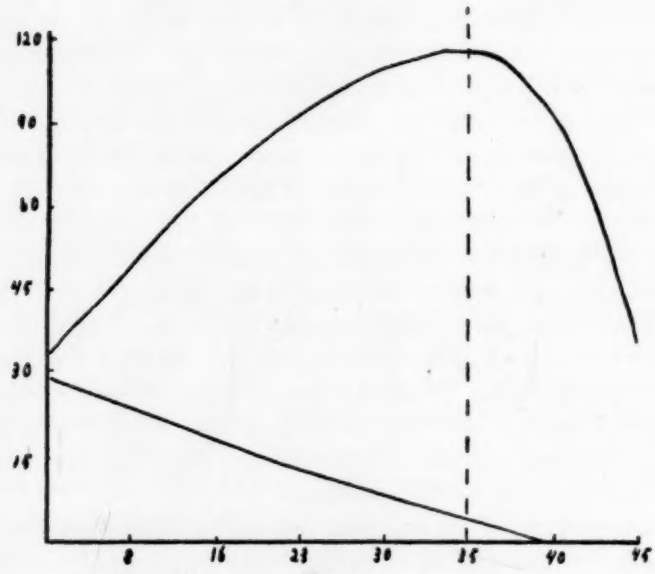

FIG. 1.

This is represented by the lower curve. Below this line, no after-effects can be secured. The duration intervals were chosen arbitrarily, and they are too large to admit of the construction of an accurate curve. The curve is based upon the facts that the period of effectiveness is less than 30 sec. for positions inside of the 16° zone, less than 15 sec. for the 23, 30 and 35½ degree positions, while a momentary fixation is effective outside of

the 40° zone. (2) There is a certain period of fixation necessary to secure the maximum of result for any position. This period varies with the position. The upper line of the figure represents this curve of maximum efficiency. The highest point of the curve — *i. e.*, the greatest time necessary to secure the maximum of result — is near the boundary line between the two zones. (3) Between the lower and upper limina of effectiveness, *i. e.*, between the two curves, the effect of any position increases in proportion to the duration of fixation. (4) After the maximum of effect has been obtained, further fixation decreases the effect. The effect for any position decreases in proportion to the height of the time ordinate above the maximum efficiency curve.

The preliminary character of the above tests is readily apparent. Merely the general character of the results has been stated. Many details and variations have been omitted. There are a number of facts which point to some such final statement as the following: Fixation of any position leaves two antagonistic effects, one tending to make the light move in the same direction and one in the opposite direction. The opposite tendency is the stronger but its duration is less than the second tendency. The duration and strength of each increases with the eccentricity of the position though not in the same ratio. The effectiveness of each for any position varies with the duration of the fixation, but not to the same degree. Such a conception is merely suggested as being the possible outcome of further experimentation.

The disturbance resulting from positions in the outer zone is very characteristic and noteworthy. The first movement in the opposite direction varies in duration from 1 to 21 seconds. It is very rapid; at the maximum speed obtained the light gave the impression of a rocket or a shooting star. Its initial velocity was often judged to be as high as 15–20 degrees per second. The subject was directed to fixate the light immediately upon the darkening of the room. The light had often moved 25–35 degrees before the eye succeeded in fixating it. This initial rapidity gradually decreases until the opposite movement stops and the return movement occurs. In this rapid phase of the

illusion there is a marked discrepancy between the apparent rate and duration of the movement and the amount of space traversed. Although the velocity may average 10° per second for at least 15 seconds, yet the light may not appear to move more than 210 cm. — an angular distance of 45°. The light moves in a series of spurts, *i. e.*, the velocity seems checked momentarily from time to time. At these moments one's idea of distance seems to undergo a transformation. During the first spurt the light moves rapidly through a certain distance, *e. g.*, 40°. During this period the extent and rate of movement are proportionate. The velocity now is noticeably checked for a moment, and at this time the transformation of conceptual space values occurs, for the light suddenly seems but 10° instead of 40° distant from its starting place. Another spurt occurs and the light now moves to a distance 45° from the center. This is followed by a second check in which the 45° instantaneously shrinks to something like 15°. This process is continued, though it is more marked in the initial phases of the movement. The above values are intended to be merely illustrative. As a consequence the light gives the impression of moving very rapidly without getting anywhere.

This opposite movement due to the extreme peripheral fixation can be obtained by subject *C* in ordinary perceptual conditions. The only difference is one of degree. The experience in daylight is very similar to that obtained by rotation dizziness.

In all the above tests the light has been located at the center of the field. The after-effects of a peripheral fixation will be the same no matter where the light is located. If '*c*' refers to the center of the field, '*a*' to some fixated position, and '*b*' to a peripheral location of the light, the general statement may be made that the after-effects of fixating '*a*' depend upon the distance and direction of '*a*' from '*c*,' and in no wise upon the spatial relation of '*a*' to '*b*.' This statement is based upon the results of numerous tests. The following are given as illustrations: (1) The light was placed 15° to the right of the center, and the eye fixated a spot 30° to the left of the center. A slow movement to the left resulted. (2) The light was placed at the center and a fixation point 45° to the left was chosen.

A sky rocket movement to the right resulted. The distance and direction of '*a*' to '*b*' were identical in the two cases, but the results were different in both direction and velocity. In the first case practically the same effects would have been obtained if the light had been located at the center of the field.

If the light is placed in some extreme peripheral position, where the illusory result is determined by the eye position during the fixation, two tendencies are apparent, that due to the position itself (see *E*) and that due to the effects of the previous position. These tendencies may enhance or neutralize each other. Consequently the illusory movement of the light at a position '*b*' is a function of the distance and direction of both '*b*' and '*a*' from the center.

The after-effects of eye position are thus a disturbing factor which must be taken into account in determining the effect of the position factor (see *E*). A small interval of time (not more than 1 min.) should be allowed between successive tests. In the interval, the eye should occupy the central position. These precautions were not systematically observed in the tests described. Consequently, it is possible that some of the variability of results in the earlier phases of the movements may be explained in this manner. Such a factor could have no influence upon the *final* direction of movement because the course of the illusion was generally observed during more than a minute's fixation.

All of the preceding results refer only to subject *C*. The observations of *A* differ in a few details. Three zones of influence were evidenced. Positions in the inner and outer zones deflected the illusion in the opposite direction. A like direction obtained for the middle zone. The boundary between the two outer zones was elliptical, the vertical axis being the longer. The limit of the inner zone was between 8°–16° from the center of the field.

Subject *F* could not experience the illusion under these conditions of induced fatigue. But few tests were taken upon subject *W*. Previous eye position was effective to some degree but its influence was not marked. The few tests made do not allow of any general statements as to the directive character of the disturbance.

Evidently the after-effects of eye position vary markedly with individuals as do the effects during fixation. The character of the after-effects apparently is related in some way to the influence exerted during fixation, because observers *C* and *A* give similar results in both experiments. The relation is not one of directive antagonism, however.

These after-effects are probably to be considered as due to ocular fatigue. Constant fixation of a peripheral position can be maintained by subjects *A* and *C* only with strain and effort. This necessary effort increases with the eccentricity of the position. Extreme positions soon induce fatigue almost to the point of exhaustion. After inducing fatigue, a rotation of the head around the anterior-posterior axis changes the direction of the disturbance. If the normal results of a fixation is a movement to the left, a 90° rotation of the head on the left shoulder will cause the light to move downward. This evidences the fact that the effects of a fixation are resident in the ocular muscles.

G. Some Factors Producing Variability of Direction.

In the two preceding experiments to determine the influence of eye position, an irregularity in speed and direction during the illusion, and a variability in direction for successive tests on the same position were noted. This variability was extremely pronounced for subjects *C* and *A* for central positions where the influence of eye position was minimal. This variability indicates the functional efficiency of other determining factors. The remaining tests were designed to determine the nature of such variable disturbing factors.

1. *Influence of Retinal Rivalry.* — The average direction of movement for monocular and binocular conditions of observation was determined for a number of positions from a series of successive tests. The average directions for the three conditions of observation differ slightly. Right or left monocular vision with subject *C* tends to deflect the direction to the right and left respectively. The binocular direction seems to be either a mean between the other two, or else to be coincident with one of them. One is not justified in making any general statement other than that some directive influence probably exists.

In binocular vision the two eyes are known to alternate frequently in visual effectiveness, *i. e.*, to approximate monocular conditions. If the direction varies for the three conditions of observation, it is probable that these frequent alternations of ocular effectiveness should result in some slight disturbances in the direction or velocity of the movements.

2. *Effect of Voluntary Eye Movements during the Illusion.* — The subject was directed to rotate the eyes from one edge of the light to the other from time to time during the illusion and to note any coincident disturbances in direction or velocity. The eyes were rotated in both the vertical and horizontal planes. The tests were performed for various eye positions. Two lights were used, a square light of 1 cm. dimension, and a light in the shape of a cross allowing movements 3° in length. The effects were similar for both lights. Frequently no disturbance was noted. A slight momentary influence of the same direction as that of the eye movement was generally present. The disturbance was momentary and never more than one half degree in extent. No permanent influence upon the direction or velocity of the illusion was ever noted. These eye movements may thus result in a slight temporary irregularity of direction or velocity.

Observations were made while attempting to fixate a distinct point in the light. These results were compared with those obtained when the fixation was allowed to wander over the light at will. No differences in direction or velocity could be noted between the two conditions of observation.

The eye was rotated toward the light from various directions at the beginning of the illusion. Care must be taken to choose such distances that no after-effect of the previous position is evident. The effect of the eye movement *per se* is desired. A slight temporary disturbance of the same direction as that of the eye movement was generally observed. No permanent effect was exerted.

The fixation was suddenly shifted for various distances and directions away from the light during the illusion. Such movements of more than 2° tend to destroy the illusion temporarily, the light appearing to be located nearer to its original position.

If the eye is held stationary in the secondary position the illusory motion again appears. The illusion is now slow and small in extent and its direction is similar to that obtained when the light is located at the secondary position. The illusion is similar to that of the second type. Subject *W* reported that during the voluntary shift the light appeared back in its original position without any sense of motion being aroused. With subject *C* the light generally returned only part way toward its initial position. In approximately half of the tests the return was accompanied by an exceedingly vague and fleeting sense of motion, a phenomenon of which one could make no very confident statement. Large and rapid voluntary sweeps of the eye away from the light during the illusion thus awaken a more accurate impression of the position of the eye in its spatial reference. They transform one's conceptual system of space. This sudden transformation of conceptual space relations often awakens an impression of a sudden fleeting motion on the part of the light. This transformation of conceptual spatial values is identical with the phenomenon observed during the rapid movements due to previous eye position.

3. *Effect of an Objective Movement of the Light.* — During the illusion the light was oscillated in the horizontal direction. The test was made for various eye positions. The extent of movement was either 30′ or 1° 20′. The rapidity of the oscillations was varied. For those positions where the illusion normally moves rather rapidly in a vertical direction, one obtains a spiral or cork-screw effect, a composite of the horizontal oscillations and the vertical movement. For positions where the light moves rapidly in the horizontal, the oscillations alternately accelerate and retard its velocity. When the illusion is normally very slow and the oscillations are quite rapid, one can detect the presence of the illusory factor, but its continuity and regularity is destroyed or rather overshadowed by the rapid oscillations. So far as can be observed, objective oscillations do not disturb the illusion in any way, for the total result is a composite of the oscillations and the normal illusory motions for that position. If any effect is exerted, it tends to decrease the velocity.

4. *Effect of Involuntary Eye Movements during Fixation.* — It is axiomatic that absolute constancy of fixation is impossible. Slight irregular involuntary shiftings of the eyes are almost continuously present. Slight eye twitchings were directly observed in these tests. Some writers are inclined to attempt a complete explanation of the autokinetic phenomenon in terms of these involuntary eye movements. The relation between these involuntary eye movements and the illusion was studied by the negative after-image method. The method was described in Sec. D. In illusions of the first type a previously induced negative after-image remains with the light and participates in the illusion. However, there are slight irregular relative movements or oscillations due to the involuntary shifts of the eye-ball. It is not contended that these oscillations give information of every eye movement, for some of these latter may be so small that the consequent shift of the light stimulus over the retina is below the spatial limen, *i. e.*, non-effective upon the location of the corresponding perceptual object. The oscillations do represent the *spatially effective* movements. The distance between the edges of the light and the concentric after-image was 1 cm. A rather accurate estimation of the length and direction of the oscillations was thus possible. A simultaneous comparison of the presence, extent and direction of the effective eye movements and the length, direction and velocity of the illusion is thus possible. A series of observations was made by subjects *C* and *A*. Various eye positions were used, and hence all typical characteristics of the illusion were studied. Oscillations occurred at some time in every test, though there were periods in which none could be detected.

Generally no effective eye movements occur during the marked and significant directional changes of the illusion. When such eye movements are present, their direction bears no constant relation to the illusory phenomenon. Fifteen observations were made during a marked and permanent change of direction. In most of the cases the direction was completely reversed. No oscillations were detected during or just previous to thirteen of these directional changes. The movement was reversed from an upward direction in the two remaining obser-

vations wherein oscillations were present. The oscillations were in the horizontal in one case, while the fixation shifted upward 5 mm. in the other.

No difference could be detected in the behavior of the illusion for the periods wherein no oscillations were present as compared with those periods in which they were detected.

The direction of the oscillations bore no constant relation to that of the illusion. As to direction the oscillations are very irregular while the illusion may be constant and uniform in this respect. Periods sometimes occur in which the illusion is very irregular in both velocity and direction while the oscillations are normal in character.

The length and rapidity of the oscillations vary markedly from time to time. The average amplitude was approximately 5 mm. around the center of fixation. No movement greater than 1 cm. (16′) was observed. No correlation could be made between the extent and rapidity of the oscillations and the velocity of the illusion. The oscillations were possibly less pronounced for peripheral than for central fixation positions. The speed, length and uniformity of the illusory movements are the greater in the former case. Observations were made during the 'shooting star' effects previously described. The oscillations were slow and small during these rapid velocities.

Oftentimes no oscillations occur, yet the light and the after-image are not concentric. In other words the light is perceived paracentrally. The extent and direction of these deviations from foveal fixation were noted in relation to the various characteristics of the illusion. No correlation between the two could be made.

On the whole, no correlation was found between the various characteristics of the illusory movements and any features of the oscillations. On the contrary, the results suggest that possibly steadiness of fixation may favor the velocity and uniformity of the movements.

In this connection it may be well to note that some observers cannot obtain the illusion under any conditions. Others find it impossible to experience the illusion for certain eye positions. One would hardly dare venture the opinion that involuntary eye

movements do not occur in these cases, that some people can maintain absolute fixation. In view of these facts, the hypothesis that regards the eye movements as the sole and sufficient explanation of every phase of the illusion is impossible. Otherwise why should the bulbular twitchings beget an illusion in one case and not in another?

One feature of the oscillations merits additional comment. Since the negative after-image corresponds to a purely retinal process, it would seem that any relative movement of the after-image and the light due to eye twitchings would be exhibited by the after-image. As a matter of fact this was not true. The oscillations were due to irregular movements on the part of the light. This fact might seem at first thought to disprove the assumption that the oscillations represent eye movements. This possible conclusion is not justified for two reasons: (*a*) No oscillations were ever observed between two concentric negative after-images. (*b*) When two lights move relatively to each other, the movement for some reason is ascribed to the smaller object. This general statement is the result of three series of observations. The first refers to the observations already reported wherein a small light was perceived in the center of a large after-image. The light exhibited the motion. In the second series, a small negative after-image was developed in the center of a large light. In this case the relative motion was invariably exhibited by the after-image. In the third series two objective lights of equal intensity but of unequal size were perceived in an otherwise darkened room. They were situated some 10 cm. (2° 45′) apart. The assistant could move either light a distance of 4 cm. The observer was allowed to fixate the lights as desired and he was requested to judge as to which light exhibited movement. Any motion on the part of the small object was correctly perceived. With a medium velocity, any movement of the large light was interpreted as belonging wholly or in part to the small object. Such complete transference of the motion occurred in 80 per cent. of the tests. If the motion of the large object be small in extent and slow and uniform in velocity, the illusory transference will persist in spite of knowledge on the part of the observer.

5. *Effect of Eye Closure upon the Illusion.* — Involuntary blinking occurs quite frequently during the course of the illusion, and from casual observation one suspects that these lid movements are influential in determining the irregularities of speed and direction which so often characterize the illusory experience. Three series of observations were made to test this point. (*a*) Blinking was inhibited for as long a period as possible. (*b*) Binocular and monocular winking was initiated voluntarily. (*c*) Prolonged and intensive eye closures were instituted. All eye positions were studied in this manner and these periods were compared with normal conditions of observation. Inhibition of the involuntary blinkings exerted no apparent influence upon any characteristic of the illusion. Voluntary winks were sometimes effective and sometimes not. The effect was more frequent for central eye positions. For peripheral positions the velocity of the illusion was occasionally checked temporarily but no directive influence was noted. A momentary disturbance of direction was observed in 50 per cent. of the tests for central positions. The direction of the disturbance varied with the eye position but it was constant for any position. The disturbance was slight and temporary, consisting of a sudden jump of about 1° on the average. A *permanent* change of direction coincided with a wink in but one case out of 50 trials. Prolonged and intensive closure gave similar results with the exception that the extent of the disturbance was greater. The effect marked merely the beginning of each successive innervation and it varied in amount with the strength of the innervation. An increase of the effect was obtained as long as the innervation could be increased in intensity.

One observation of *A* is noteworthy. The light had moved several feet. After winking, the light appeared to be only a few inches distant from its starting point. This is another illustration of that sudden transformation or rather shrinking of space values which we have previously noted.

6. *Voluntary Control of the Illusion.* — Charpentier noted that the direction of the illusion could be modified voluntarily while still maintaining fixation of the light. He accomplished this result by thinking of or peripherally attending to some

object located in the desired direction, or by thinking of performing a movement in this direction. All observers were able to produce the effect at times. No observer could secure the result in every trial. A sudden and unexpected sound often deflected the light in its direction. Bourdon reports the same results with several subjects. The effect was secured with difficulty in some cases. A preliminary movement of the eyes in the desired direction was serviceable in securing control. The effect often persisted only during the voluntary effort.

The possibility of voluntary control was confirmed by our tests. The control may be exerted upon either the direction, velocity or extent of the movements. Subject *W* was unable to secure any effect. Apparently the degree of control possible varies with individuals. Voluntary influences are more effective for central eye positions. The control is never complete or absolute. Certain given determining conditions are always present in comparison to which volition is relatively powerless. Volition is rarely ever immediately effective. Its influence is manifested slowly and the effect gradually increases during a prolonged effort. The disturbance of direction is temporary if the voluntary effort is exerted but for a short period. After the movement once gets well started along the desired direction, the effect may be relatively permanent, *i. e.*, the deflected direction may be maintained after the effort has ceased. The difficulty involved in voluntary control seems to consist in getting the desired movement started with a sufficient momentum. The light gives the impression of possessing an inertia difficult to overcome. Once the light gets thoroughly started, its own momentum carries it forward.

From the standpoint of explanation, the crucial point is not the *fact* but the *mechanism* of voluntary control, a question which has not been considered in previous treatments of the autokinetic phenomenon. Our introspective observations indicated that innervations or strain sensations of certain ocular and facial muscles are necessary and essential to volitional control; that mere volition, *i. e.*, the idea of the proper direction and the mere fiat or intellectual decision, is functionless; that the effect occurs only when the volition is translated into appropriate motor terms and

that the degree of effect secured is proportionate to the intensity and direction of these motor tensions.

In voluntarily deflecting the movement to the right, there was a rightward ocular strain which often became painfully fatiguing. The trunk of the body became set and rigid, the breath was held, the jaws were firmly set and the facial muscles were twisted and pulled over in the desired direction. With a downward deflection there was an appropriate pull of the ocular muscles, and the facial muscles around the cheeks, eyelids and brows participated in the downward movement. The secondary contractures of the muscles of the jaws and the trunk of the body were also present. The eyes did not move because they were innervated antagonistically. Yet the antagonistic innervations did not seem equal, the surplus of one, as it were, overflowing into the surrounding muscles. These facial contortions were directly observed.

The necessity of these tensions was indicated by the fact that they were invariably present, that the degree of influence exerted was proportionate to the intensity and extent of the contractures, and that the attempt to control the illusion without concomitant strain sensations was unsuccessful.

A series of tests was made to determine the functional efficiency of motor tensions upon the illusion. While observing the illusion in a normal manner, various groups of muscles were strongly innervated without any thought of or attempt at volitional control over the illusion. All resulting disturbances were noted.

(*a*) The light was placed in a central position for which the normal behavior of the illusion was known. While observing the illusion the subject was asked to listen passively to some continuous sound located in a peripheral position of the field. Passive attention means a mere awareness of the nature and position of the sound without the presence of any ocular or auricular tension. No influence on the illusion was noted.

The subject was requested to give active auditory attention to the sound. This involved auricular attention with no ocular strain. A prolonged and intensive effort of such a character generally deflected the illusion to a slight degree in the direc-

tion of the sound. The result was not pronounced nor did it occur immediately.

Visual and auditory attention was initiated. The subject was requested to listen intently and to visualize the position of the sound. As a rule a deflection of the illusion in the direction of the sound occurred. An appropriate eye-strain was generally detected in the effective tests.

(*b*) All of the muscles of one hand and arm were vigorously contracted. The attempt was made to confine the innervation to these members exclusively. Slight disturbances were noted in the majority of the tests, the extent and direction of which were irregular.

Deep and slow breathing was instigated, the breath being held as long as possible. Unequivocal results were obtained in but one test. Inspiration deflected the movement upward, a return movement accompanying the expiration. This oscillation occurred for every act of respiration in this particular test. Subject *A* could obtain no results.

A strong contracture of the jaws produced a noticeable downward deflection of the movement under all conditions. A release of the tension was followed by an upward movement. The effect was quite pronounced and it followed the innervation almost immediately. No influence was obtained by subject *A*.

A binocular strain of the eye as represented by 'staring hard' at the light gave a very slight downward effect in some cases. A similar monocular innervation produced an effect in the majority of cases. For the left eye, the deflection was down and to the left. The deflection for the right eye was down and to the right. These statements refer to subject *C*. Different directional results were obtained by *A*.

A unilateral strain of the eye in any direction resulted in a pronounced deflection in that direction. This refers to a pull or strain on the eye in a lateral direction without any consequent deviation of fixation. A pronounced strain of this character involves facial contractures in the same direction. The disturbance was proportionate to the intensity and duration of the innervation and the number of facial muscles involved.

The direction of the illusion for central positions may be permanently reversed by a continuous and intensive effort of twenty seconds duration. In fact, the illusion may be almost completely controlled for central positions. Marked alterations of direction and velocity can be effected for peripheral positions.

Fixation of extreme peripheral positions can be maintained by subject *C* only by strenuous effort which is painfully fatiguing. By alternately relaxing and increasing the innervating effort without deviation of fixation, the light can be made to vibrate to and fro through a distance of 7°–8°. The velocity of the movement can be controlled by regulating the degree of innervation. In this case the eyes are not strained away from the light, as described in the previous paragraph. The effort is directed rather toward a maintenance of the fixation.

Fatigue resulting from a prolonged ocular tension produces marked disturbances whose direction is opposite to that of the strain. While the room was illuminated, the observer fixated the light and strained the eye in some direction. These tensions were maintained for periods of thirty to sixty seconds. The subject was directed to relax the tension at the moment the room was darkened, but still to maintain the fixation. The illusion was observed and compared with the norm for that eye position. The illusion was deflected in a direction opposite to that of the strain in 75 per cent. of the tests. The duration of the disturbance varied from 30 sec. to 2 min. The effect was more pronounced for strains to the right or below.

A number of observations were made during a condition of a constrained position of the head in relation to the body. The body was twisted so that the line of vision was directed over one shoulder. The head and the eye maintained their normal positions in reference to the light and relative to each other because of the head rest. The illusion under these conditions was compared with the norm for a number of positions. Subject *C* reported a possible disturbance for some positions. The results were too slight to admit of any confident assertions. Observer *A*, however, reported an average deflection in direction of 45° in 90 per cent. of the tests. The direction of the disturbance was always opposite to that of the body torsion.

Charpentier has reported that with monocular observation, finger pressure upon the closed eye produced deflections whose direction was dependent upon the character of the pressure but independent of the position of the eye in the socket. Our tests did not confirm these results in *toto*. The direction of the disturbance was dependent upon both the direction of the pressure and the eye position. The amount of deflection varied from 30′ to 5°. The influence was temporary and it occurred only at the beginning of the pressure. Inasmuch as the pressure is exerted upon the closed eye, it is difficult to conceive how the vision of the opposite eye can be effected unless through the medium of the binocular tension. Binocular adjustment is unitary and any force exerted upon one eye must necessarily effect the tension of the other eye. A readjustment of binocular innervation is needed to resist the interrupting force.

The effect of prolonged and intensive eye closure described in Section 5 is similar to the above phenomena and may be adduced in support of the theory of innervation. An influence was noted at the beginning of each successive innervation of the lid muscles of the closed eye. The effect varied with the strength of the innervation. That is, this effortful contracture of the closed eye influences the illusion as experienced by the opposite eye.

H. Theoretical Summary.

One common theory attempts a *complete* explanation of the illusion in terms of the involuntary eye movements. These small movements which are highly irregular in direction and extent are conceived to be integrated in some fashion so as to mediate the sense of a large and continuous movement of the light. This theory may be conceived of in two ways: (1) That the effective principle is the consequent retinal shiftings of the stimulus which awaken the sense of motion and which are combined into a continuous whole. The eye movement theory is generally stated in such terms. (2) The effective factor may be regarded as the fluctuating motor tensions which lead to the eye-movements. This paper admits that such eye-movements may play some minor rôle in the illusion, but it denies that they may be regarded as the only or the most important factor in the phenomenon.

Theoretical considerations may be urged against the theory as the *sole* explanatory principle. Why should the eye movements become integrated? What is the mechanism of this unconscious integration? Why does not the integration occur under normal conditions of perception? How and why should the process of integration be modified by the factor of position, etc.? Why should the process of integration achieve such diverse results under similar conditions? Factual objections may be given. Some people cannot experience the illusions under any circumstances. Some people can obtain the phenomenon for some eye positions, but not for others. The illusion does not occur in normal perception. No one can deny the presence of involuntary eye movements under these conditions. If eye-movements produce an illusion in one case and not in the others, at least some secondary principle of explanation is necessary. The conception to our mind is simply preposterous.

The experimental facts on the oscillation of the light and negative after-image are adduced against the contention that these eye movements are the most important causal factor. It may be objected that the test is faulty inasmuch as only the spatially effective eye movements were correlated with the illusion, that many minimal movements escaped detection. The objection may be granted without necessarily invalidating the argument. (1) If the large eye movements, as our results indicate, are practically without function, it is illogical to ascribe any pronounced effectiveness to the minimal movements. (2) The contention is rather inconsistent in that it assumes that eye movements which are *spatially non-effective* as to oscillations are yet spatially effective in that they produce the illusion.

Other facts than those given in the section on oscillation may be cited. A series of observations in which a small point on the light was fixated was compared with one in which the eyes were allowed to wander at will over the surface of the light. The eye movements were probably more pronounced in the latter case. No difference in the behavior of the illusion in the two cases was detected. In all probability the eye movements were accentuated when the light was moved objectively, but the illusion was retarded. Retinal shiftings of the stimulus occur in

the voluntary rotations of the fixation over the light, in the winking test and when the light was oscillated. These retinal shifts were sensed as motion, but the movements were not incorporated as an integral part of the illusion. They stood out independent, as additions, as disturbances; they were not undiscriminated parts of a continuity. If a series of irregular shiftings due to involuntary bulbular twitchings can be integrated to form a one-directional unity, as the theory assumes, it would seem that these shifts due to winking, voluntary rotation, etc., should be incorporated more successfully into the integrated whole. The fact that they are not so incorporated leads one to question the integration theory. The results on the oscillations of the negative after-image indicated that, if anything, steadiness of fixation favors the velocity and uniformity of the illusory motion, that the retinal shiftings due to involuntary rotations are to be regarded as disturbing elements, and that integration does not occur.

In the way of a positive contribution to a theory of explanation, our experiments reveal four effective factors which are influential in determining the direction, velocity, and continuity of the illusory movements. (1) The position of the eye in its socket; (2) the after-effects of eye position; (3) motor strains as exemplified in the tests on voluntary control, and (4) the after-effects of such strains. The mutual relations of these four conditions are to be considered.

The second and fourth are similar in that the after-effects which are so influential upon the perceptual experience must be considered as resident in some way in the neuro-motor mechanism. Compare a normal illusion with that obtained for the same position after a previous constrained position or a unilateral strain on the eyes. Radically different illusory results are obtained in the two cases. The effects cannot be ascribed to a difference in the sensory conditions of the observations, for these are similar. The after-effects are independent of the position of the eyes in the socket. Turn the head on the shoulders and the direction of the illusory disturbance is changed. The after-effects must be resident in the neuro-muscular mechanism. It is immaterial whether these effects be termed fatigue

or whether they be located in the muscle or in the motor centers. The purport of the facts indicates that different neuro-muscular conditions of observation give diverse illusory results.

The first and third factors are similar in several respects: (1) they both involve effort and strain, (2) the light moves in the direction of the strain, and (3) the illusory effect varies in direct proportion to the degree of strain involved. For the third factor these statements are a summary of the section on voluntary control. Their application to the position factor needs additional comment. Observers *A* and *C* can maintain a peripheral fixation position only by a strenuous effort which, if prolonged, becomes painfully fatiguing. The eye tends continually to move back to a more central position. The effort is directed peripheralward and the resulting illusion is in this direction. The degree of effort involved varies directly with the eccentricity of the position, as does the illusory effect. In illusions of the second type, *i. e.*, those due to eye movements, the eyes are invariably forced back toward the center of the field. The contention that the eyeball encounters a resistance in assuming and maintaining any peripheral position, and that this resistance varies in amount and character with the position is supported by the results of a previous paper on the winking illusion. This illusion was found to be due to an enforced eye movement whose direction and extent varied with the eye position. The eye-ball is not a perfect sphere and its rotary and geometrical centers do not coincide. The surrounding fatty tissues thus offer a resistance which tends to force the bulb in a characteristic direction for any position of the eye in the socket.[1] Now eye position, for our three subjects, exerts the same influence upon both the autokinetic and the winking illusion, *i. e.*, the force exerted upon the bulb in any position by the surrounding tissues is proportionate and antagonistic to the extent and direction respectively of the autokinetic illusion. The muscular effort involved in overcoming this resistance in assuming and maintaining a position is thus directly related to the resultant illusory motion. The autokinetic phenomenon may thus be regarded as due to the elements of strain and effort involved. The effective prin-

[1] Carr, *ibid.*, pp. 75-77.

ciple may be either the neuro-muscular tension or the resulting sensory experience involved in maintaining the bulb in a position against the resistant forces of the fatty tissues.

If an altered condition of the neuro-muscular mechanism resulting from previous activity can modify the illusion, it would seem that the previous neuro-muscular tension itself should be highly effective. Now the illusory effects of tension are directly related to the after-effects of that tension. This fact leads to the assumption that the effective principle in strain and effort is rather the neuro-muscular tension than the resulting sensory component. This view would possess the advantage of unity and simplicity, in that it reduces all four effective factors previously enumerated to the one principle, *viz.*, that the autokinetic illusion is mainly determined by the changing neuro-muscular conditions involved in a continuous fixation. From the standpoint of this article, however, there is no objection to ascribing a functional efficiency to the sensory component involved.

The sense of motion is our awareness of a change within a system of space relationships. Motion is relative. The fixated light must move in *reference to something*. This does not mean that the subject must necessarily be overtly conscious of the basal term and its space relation to the moving object. It does mean that the basal term must be represented at least in the background of the total experience. Its existence is necessary to mediate the sense of motion.

In illusions of the first type, the point of fixation participates in the movement. The illusion refers to the object of foveal consciousness. The light cannot move in reference to any other visual object, for no visual points of reference exist. This possibility is excluded by the conditions of the experiment. The only possible basal term of reference is the space feeling of the body as represented by the kinesthetic and organic sensations and the tactual experiences due to contact with objects in the room. In these conditions of perception, the object of foveal activity stands in a constant space relation to the eye. This fact was demonstrated by the tests on eye movement. Consequently the eyes are the only possible means of connection between the visual object and bodily space. The eyes,

tactually and kinesthetically considered, are a part of the bodily space. A correct definition of the position of the visual object relative to the body thus depends upon a correct appreciation of the eye-body relation. Any unusual conditions of the eye-body relation must result in an erroneous sense of the position of the fixated light in reference to the body

The point of fixation appears stationary with respect to bodily position in the second type of the illusion. As a matter of fact it has moved because the eyes have undergone rotation. The fundamental fact is not the apparent motion of the light but the *lack of motion* on the part of the fixation point. The illusion occurs on account of an erroneous sense as to the spatial relation of the point of fixation in reference to the body, and this is mediated through an erroneous appreciation of the eye-body relation. Both types of illusion are to be explained on a similar basis.

The above situation may be contrasted with that of normal perception. The point of fixation or the visual field in both cases stand in a given fixed relation to the bulb. In normal perception, the mutual definition of the visual and the organic space systems depends upon several coöperating factors: (1) Certain objects appear in both space systems. The brows, nose, hands, feet, etc., are both seen and felt. The body as felt is often in direct contact with objects seen. The hands are moved to touch and explore the visual objects. The two systems of space experiences thus overlap. Mutual adjustments and definitions are rendered not only potential but necessary. (2) Steady fixation rarely ever occurs. Through movements of the eyes, head or body, objects are continually entering into and disappearing from visual space. (3) Kinesthetic-tactual cues as to the eye-body relation are furnished by pronounced eye or head movements. Inasmuch as the visual space occupies a given relation to the eye, any appreciation of the eye-body space relation organically sensed aids the mutual definition of the bodily and visual space. By these three means one develops a rather accurate mutual definition of two space experiences. One's definitive reactions come to be relatively immediate, automatic and habitual. The attention is centered upon the results

and not upon the sensory means, or cues. The position of any foveal object is immediately defined in terms of right or left, above or below. (4) Each rotary eye adjustment, or ocular attitude, must develop in time from the above sensory cues a certain spatial meaning or significance, whereby it is possible, if necessary, to define the direction of fixated objects and to adapt the body thereto. These ocular attitudes form a fourth means for the mutual definition of the two systems of space. Inasmuch as our spatial definitions become immediate and automatic, it is probable that these motor attitudes play an increasing rôle in the ordinary adjustments to visual space.

In the autokinetic illusions, the first three of the above mediating connections are excluded by the conditions of the observation. Only the light is seen. Neither the body nor the objects in contact with the body are perceived. Constant fixation is maintained. The head and body are stationary. No new objects can enter the visual field. Eye or head movements sufficient to arouse adequate kinesthetic-tactual cues are eliminated. A continuous ocular attitude forms the only link between the two space worlds. All definitions of direction must be made on the basis of the spatial significance which these motor attitudes have already attained. Naturally the potential value and accuracy of such a mediating factor may vary with individuals.

The theory assumes that this remaining link, the motor attitude, may be modified by various influences during the course of a long fixation so that its directional significance is gradually altered. As a consequence the subject's definition of spatial relation undergoes gradual transformation and an illusion of motion results. A position which at first seems to be directly in front of the observer is finally defined as being to his right. Since it is the *meaning* of the ocular adjustment that changes, thus giving rise to the illusion, it is proper to say that it is one's *idea* of direction which is altered, or that it is one's visual *conceptual space world* which, in reality, moves. It does not follow from this proposition, that the directional position of the light is completely subject to voluntary control, varying at the slightest wish. Ideas possess their given fixed characteristics to varying

degrees. The idea of direction can be changed only by altering or modifying in some way the character of the underlying motor-adjustment, as was exemplified in the section on voluntary control. Complete or absolute control would only be possible when all four connecting factors were destroyed.

This general conception is supported by several observations already described. If any of the three connecting cues excluded by the imposed conditions are suddenly introduced, a quick transformation of directional values results. The light has apparently moved thirty degrees to the right. Illumine the room and this sense of 'rightness' is immediately transformed to the 'in front feeling.' The given relation of the light and the body has remained unaltered throughout. The changes have occurred in the directional significance of the light as expressed in verbal or bodily reactions. The change has been one of motor interpretation. Rotate the eyes, wink, or press upon the bulb sufficiently to awaken tactual cues as to the eye position, and one's idea of direction based upon a fatigued ocular attitude is modified and corrected to some degree. This process of modification, or of transformation of space values occurring during the illusion, also temporarily destroys the illusory motion, checks its velocity, or awakens a sense of a return movement. If a sudden change in one's idea of direction can destroy or check a movement, or even substitute in its place a sense of motion in the opposite direction, the assumption that the original illusory movement is due to a gradual change in the idea of direction is not illogical. These sudden revaluations of directional significance occurring from time to time during the illusion are but special cases of the gradual alterations which produce it.

Such a conception presents difficulties but it systematizes and unifies the facts rather successfully. Inasmuch as the eyes normally are in almost constant motion, their acquired spatial meaning is based upon a merely temporary fixation. During a prolonged fixation fatigue occurs and the attitude from the standpoint of volition keeps gradually changing. Objectively speaking, the adjustment does not vary, but this fact does not matter. It is the functional, the dynamic attitude that is important. The psycho-physiological mechanism of adjustment does vary. The

fatigue effects due to previous strain are likewise influential inasmuch as they demand compensatory adjustment. The strains and efforts cited under the section on voluntary control simply represent an abnormal adjustment. In illusions of the second type, the motor attitude is maintained though the eye-ball and consequently the fixation point do move. The point seems to maintain the same position throughout. The illusory interpretation of the position of the fixation leads to an erroneous interpretation of the position of the light. In such a theory involuntary eye movements can play but little part. Any movements large enough to awaken tactual cues would tend to destroy the illusion. The consequent retinal shiftings would be represented as disturbing fluctuations. If any aspect of these movements were integrated into the illusion, it would be the fluctuating motor tension. Outside of this, steadiness of fixation or lack of movement, will favor the velocity and continuity of the illusion.

ANNOUNCEMENT.

The first number of a new monthly, the *Journal of Educational Psychology*, is announced for January. The editors are W. C. Bagley, J. Carleton Bell (managing editor), C. E. Seashore, and G. M. Whipple (subscription $1.50; Williams and Wilkins, Baltimore, publishers).